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CRYSTALLOGRAPHIC RELATIONS BETWEEN CUBANITE SEGREGATION PLATES, CHALCOPYRITE MATRIX, AND SECONDARY CHALCOPYRITE TWINS

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ABSTRACT

The orientation of cubanite plates unmixed from chalcopryite have been said to parallel $\{111\}$ of the chalcopryite matrix, but the best method hitherto used to determine this does not lead to a unique solution. In this paper, the orientations of the cubanite plates as well as certain twin lamellae, occurring in the coarse grained chalcopryite from Corinth, Vermont, are uniquely determined by a study of the traces of these features on two polished surfaces.

The general method of determining the pole of a plane making traces on two datum planes is discussed with the aid of the stereographic projection. The method is then applied to the cubanite and twin lamellae traces, resulting in a composite stereographic projection of these features. The orientation of the chalcopryite crystal containing these is determined from the symmetry of this composite projection. This, in turn, permits the poles to be easily indexed. Cubanite plates are found to be parallel to $\{111\}$, as previously surmised. Two new twin lamellae are discovered, the first, parallel to $\{110\}$, called *grid twins*, the second parallel to $\{101\}$, called *echelon twins*, the names being descriptive of the habit of the lamellae. Both groups of lamellae are secondary, resulting from plastic deformation. The possible causes of this include external forces, unmixing stresses, and possible inversion stresses.

INTRODUCTION

Cubanite-chalcopryite intergrowths have been shown by Schwartz¹ to arise by unmixing of an originally homogeneous phase. In chalcopryite-rich intergrowths, the cubanite segregate occurs in the form of plates whose intersections with the plane of a polished section have lath-like outlines. It has been surmised that these plates have the orientation of $\{111\}$ planes in the chalcopryite matrix. Twinning of the chalcopryite accompanies this intergrowth; the

¹ Schwartz, G. M., Intergrowths of chalcopryite and cubanite: experimental proof of the origin of the intergrowths and their bearing on the geological thermometer; *Ec. Geol.*, vol. 22, pp. 44-61, 1927.

nature of the twins is unknown except that some of the lamellae have been surmised to follow $\{111\}$. In order for these data to be useful in crystal structural interpretations, it is very desirable for them to be accurately established by a systematic investigation. In the present paper, both the orientation of the cubanite plates in chalcopyrite and the nature of the chalcopyrite twinning is unequivocally established.

LITERATURE

Cubanite orientation. The recorded evidence for the orientation of the cubanite segregation plates in chalcopyrite leaves much to be desired. The best evidence was offered early by Kalb and Bendig, when cubanite still went under the name of chalmersite and the origin of the intergrowth was not yet established. They said:²

In the collection of the Mineralogical Institute, a piece of massive chalcopyrite from Tunaberg, Sweden, appeared to us remarkable because of outstanding parting parallel to the faces of the unit sphenoid.

	(111):(1 $\bar{1}$ 1)	(111):(11 $\bar{1}$)
measured	70°14' ± 15'	71°8' ± 30'
calculated	70°7'	71°20'

On each parting surface, there were to be observed parallel to the traces of the three others, dark, tarnished, stripes [cubanite].

This evidence is not quoted by Schwartz, who independently deduced the orientation of the cubanite plates on the following basis:³

... the laths at any one place are either parallel or in parallel sets which make angles approximately 60° with one another. The last fact suggests to the writer that the blades or laths are parallel to the parting planes which may be conspicuously developed in chalcopyrite found with cubanite as at Parry Sound.

and again, (p. 57)

As a rule, however, the cubanite as long laths is oriented along the (111) planes in the chalcopyrite. . . . It is obvious that the cubanite is oriented along the sphene (111) planes in the chalcopyrite, and the writer has shown that chalcopyrite may show well developed parting along the same planes.

Ramdohr,⁴ Schneiderhöhn,⁵ and Schneiderhöhn and Ramdohr⁶

² Kalb, Georg, and Bendig, Maximiliane, Chalmersit von Tunaberg in Schweden: *Centralblatt für Mineralogie*, etc., 1923, p. 643.

³ Reference 1, p. 47.

⁴ Ramdohr, Paul, Neue mikroskopische Beobachtungen am Cubanit (Chalmersit) und Überlegungen über seine lagersstätten kundliche Stellung; *Zeit. prakt. Geol.*, 1928, p. 170.

also assert that the cubanite plates are oriented parallel to $\{111\}$ of the chalcopyrite matrix, but without giving specific authority or reasons.

None of the evidence offered actually established the orientation of the cubanite plates. Schwartz's observations establish practically nothing, and Kalb and Bendig's evidence does not lead to a unique solution; for example, the pseudocubic combination of plates along the basal pinacoid and second order prism is not eliminated. The planes of this combination are quasi-equivalent in low-temperature chalcopyrite and are probably rigorously equivalent in high-chalcopyrite. (See footnote 13.)

Twinning lamellae. Schneiderhöhn and Ramdohr⁷ recognize two kinds of twin lamellae in chalcopyrite. The first, a coarse banding, is said to run parallel to $\{111\}$. This is sometimes a primary growth twinning, sometimes a secondary pressure twinning, as indicated by relation to cracks and other cataclastic features. Recorded artificial production of this is still lacking. Schwartz⁸ suggests that the parting observed in the Parry Sound chalcopyrite may be due to a twinning on $\{111\}$.

The second type of twinning is manifest in finer lamellae, and its significance is unknown. Schneiderhöhn and Ramdohr suggest that this is inversion twinning (as in the cases of leucite, boracite, cristobalite, etc.) from which it might be tentatively inferred that there is an isometric, high temperature form of chalcopyrite. (Footnote 13.)

Finally, it should be noted that Dana-Ford⁹ records the following twin-laws for chalcopyrite:

- (1) Twin plane, $p(111)$
- (2) Twin plane, $e(101)$
- (3) Twin plane, $m(110)$

⁵ Schneiderhöhn, H., The mineralogy, spectrography and genesis of the platinum-bearing nickel pyrrhotite ores of the Bushveld igneous complex; (Included in Percy A. Wagner, The platinum deposits and mines of South Africa, 1929), p. 229.

⁶ Schneiderhöhn, Hans and Ramdohr, Paul, *Lehrbuch der Erzmikroskopie*, II, 1931, pp. 349 and 361.

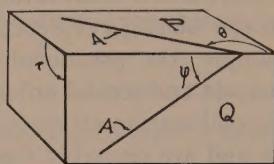
⁷ Reference 6, p. 348.

⁸ Schwartz, G. M., Primary relationships and unusual chalcopyrite in copper deposits at Parry Sound, Ontario: *Ec. Geol.*, vol. 19, p. 211, 1924.

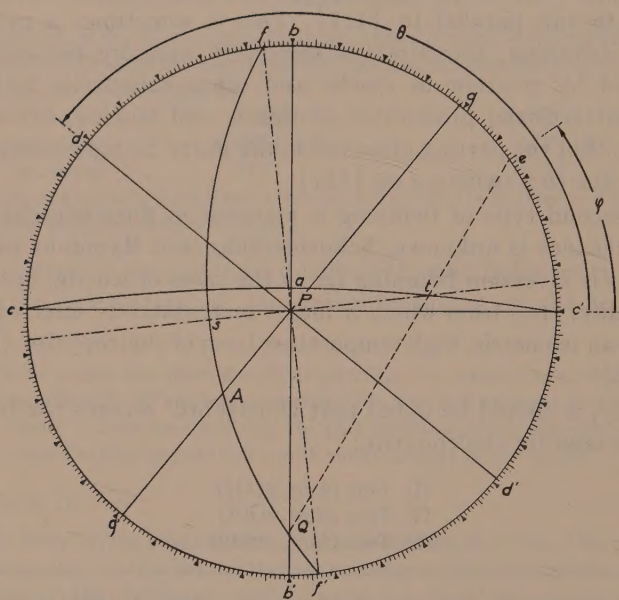
⁹ Dana, Edward Salisbury, and Ford, William E., A textbook of mineralogy, 4th edition, 1932, p. 431.

GEOMETRICAL METHOD

The cubanite plates are visible as strip-like traces on polished surfaces of a chalcopyrite crystal. The same is true of the chalcopyrite twin lamellae. Given the traces of a plane on each of two



A



B

FIG. 1.

located polished surfaces, the orientation of the plane is completely fixed. This problem is conveniently handled graphically with the aid of the stereographic projection, as follows:

Figure 1A is a block diagram showing the traces of the desired plane, *A*, on the located surfaces, *P* and *Q*, which intersect at an

internal angle, τ . The plane A gives rise to a trace on the plane P which makes an angle θ with the intersection of P and Q , arbitrarily measured counterclockwise. The trace of A on Q makes an angle ϕ with the intersection of P and Q , arbitrarily measured counterclockwise.

Figure 1B is a stereographic projection of this case. The direction of intersection of the two located planes, P and Q is arbitrarily placed left and right; the poles of this intersection then appear in the projection on the fundamental circle at points c and c' . The locus of planes which can intersect in the edge PQ is the great circle bb' . For convenience one of the planes, P , is placed horizontally, so that its projection appears at point P (the north pole). The supplement of the intersection angle, τ , is then laid off in the zone bPb' , which locates the pole of plane Q in the projection.

The direction of trace of the desired plane A with plane P appears in the stereographic projection as the line dd' . All planes capable of intersecting the plane P at this angle θ must lie along a zone at right angles to the line dd' , namely along gg' .

A similar construction can now be carried out for the possible planes, A , which give rise to the trace on the plane Q at an angle ϕ , but in this case the construction becomes more general. The intersection of the plane Q with the sphere is first located by drawing the great circle cac' . The locus of all possible intersection directions, ϕ , is this great circle. The projection of the intersection at any particular angle ϕ is found by stereographically laying off the angle ϕ from the fundamental circle along this great circle cac' . The angle ϕ thus appears on the projection as the distance $c't$, locating the desired trace direction at t . This last operation is conveniently accomplished by laying off $c'e$ equal to the angle ϕ , and at e drawing line eQ , Q being the angle point of zone cac' . The poles of all planes capable of intersecting Q to give a trace t lie at 90 degrees from t ; i.e., along the great circle fsf' .

Since all planes capable of intersecting plane P in angle θ lie along the zone gPg' , any plane A which simultaneously gives rise to both of these traces must have a pole restricted by both of these loci. The pole of the plane sought is therefore at the intersection of these two zones fsf' and gPg' , namely point A .

MATERIAL

The investigation here presented was carried out on coarse chalcopyrite ore from the Pike Hill Mine, Corinth, Vermont. The

intergrowth in this ore is substantially duplicated in the ores of the Ely Mine and the Elizabeth Mine, which together constitute the three chief deposits of the Orange County district. The mineralogy of these ores will be more fully described in a subsequent publication.

CUBANITE PLATES

The maximum number of distinct non-parallel cubanite plate traces visible on a polished section surface in a single grain (resolved by etching, as indicated beyond, and checked by reflected polarized light) was found to be four. A block of rectangular parallelepiped shape, .6×.6×.8 inches was therefore cut and polished from a region of a polished section showing this maximum number of traces, and the entire investigation carried out on a single crystal occupying a corner of this block, and which, thus truncated, constituted the major bulk of the volume of the block itself.

Cubanite is visible against chalcopyrite without artificial aid, but is rendered very distinct by etching with the following solution:

12 cc. concentrated $K_2Cr_2O_7$
100 cc. water
3 cc. concentrated H_2SO_4 , specific gravity 1.84.

By suspending the specimen so that the entire corner or edge under observation is immersed in this solution, a 10-minute etch brings the cubanite out as a dark blue against the normal yellow chalcopyrite background.

This etch is only incidentally used for bringing out the contrast between cubanite and chalcopyrite. It was primarily designed to bring out twinning and grain structure in chalcopyrite. For this purpose it is unexcelled, but the effectiveness of the etch is variable with chalcopyrite from different localities. Evidently this is due to variability in the composition of chalcopyrite from various sources. It is possible that incompletely unmixed chalcopyrite etches well, due to greater free energy, while that nearer to equilibrium, poorly. In favorable instances a 10–30 minute immersion brings out orientation differences due to grain boundaries and twinning, in brilliant collors. Even in unfavorable cases, the anisotropic effect of the chalcopyrite, seen in reflected, polarized light, is intensified by a short-time etch.

Before etching, the interior angle τ between the two planes P

and Q was measured on a single circle goniometer and found to be 93° . The specimen was subsequently fixed in a square wooden mounting so that each surface P and Q could be brought at right angles to the microscope axis by the mere process of laying the mount on the appropriate surface. This obviated the necessity of remounting when it was desired to change the surface under examination; this aided in maintaining the cleanness of the etched surfaces. Before mounting, the specimen was immersed in the etch solution for the required period, washed, and allowed to dry. Following this it was mounted, and fixed to the rotating stage of a polarizing metallographical microscope, with the edge, PQ , parallel to one of the translation screws of the mechanical stage accessory.

TABLE I

TABULATED AVERAGE DATA USED IN FIXING THE ORIENTATIONS OF THE CUBANITE PLATES IN THE CHALCOPYRITE MATRIX

	Angles made by various traces				
	with edge PQ		with edge QR		with edge PR
	face P	face Q	face Q	face R	face R
Cubanite band A	99.2°	36°	129.6°	74.4°	171.1°
Cubanite band B	71.6°	133°	58°		161.6°
Cubanite band C	31.4°	61.6°			
Cubanite band D	139.3°	109.2°			

Solid angle $PQ = 93^\circ$

Solid angle $PR = 88^\circ$

Solid angle $QR = 90\frac{1}{4}^\circ$

The four cubanite plate possibilities have been designated as A , B , C , and D . The angles of the traces of each of these with the edge of the polished surfaces, PQ , were measured as follows: First the translation screws of the mechanical stage were manipulated to bring the apex of the angle formed by the trace, A , and the edge, PQ , to the center of the cross-hairs and translation readings taken. When the second surface was subsequently studied, the translation reading was, of course, identical for this same plate, and the reading thus served to identify the individual cubanite plate under observation. This correlation was later checked by actual perspective observation of the edge, with the aid of a binocular microscope.

The difference between the stage settings when first the edge of the block (a constant for the mounting) and then the trace of the cubanite plate, coincide with a cross-hair, with the rotation taken in a counter-clockwise direction, gave the angles θ and ϕ for each cubanite plate. The averaged values of these data appear in Table I.

For each of the four pairs of averaged values of θ and ϕ , a stereographic projection has been prepared according to the method outlined under *Geometrical Method*. Each solution indicates the orientation of one cubanite plate in the chalcopyrite matrix crystal. Each of these four planes has been transferred to the composite projection of figure 4. The interpretation of this will be deferred until after a discussion of the twin lamellae.

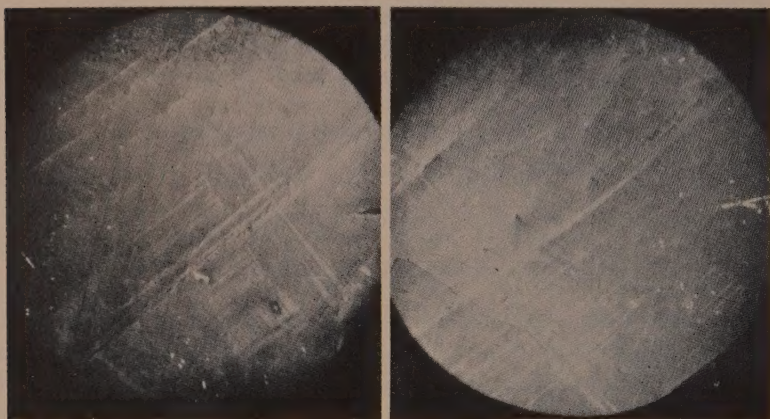


FIG. 2. *Grid twin* lamellae on polished (001) surface of chalcopyrite, brought out by etching 3 minutes with etchant. Crossed nicols, $\times 28$. A belt of cubanite bands runs parallel to one lamellae direction in each photograph.

CHALCOPYRITE TWIN LAMELLAE

Two types of twin lamellae occur in the Pike Hill chalcopyrite. These have been designated by the writers as the *grid twins* and the *echelon twins*.

The grid twinning occurs on the faces P and Q of the specimen as a series of bands parallel to the intersection edge PQ . On an auxiliary face, R (which subsequently proved to be almost exactly (001)), ground and polished at right angles to both P and Q , this twinning occurs as a grid of intersecting bands. Grid twinning is illustrated in figure 2.

There is a maximum of two sets of *echelon* groups present on any face. The word group as here used refers to a strip of disturbed chalcopyrite bounded by approximately parallel lines. This strip, in the simplest and most common occurrence, is crossed obliquely by a single set of polysynthetic twin bands, figure 3. The entire group, therefore, has the appearance of short twin bands placed accurately *en echelon*. Each individual twin band is bounded by lines parallel to two directions: (1) the common edge of the strip, and (2) the long direction of the individual bands. This gives the individual band the appearance of a distorted lozenge. For any polished surface on which this twinning is visible, there are therefore two measurable angles to be derived from each group, namely

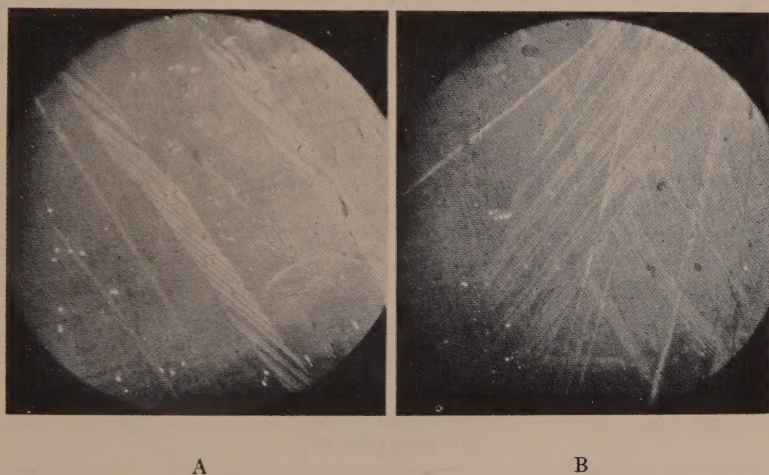


FIG. 3. *Echelon twin* lamellae, on surface of chalcopyrite polished parallel to c axis, and brought out by etching 3 minutes with etchant. Crossed nicols, $\times 28$. Figure 3A shows a set of two wide and one narrow group of *echelon twins*, with a cubanite band almost parallel to these. The faint, dark, broad bands running across the field, transverse to the *echelon twins* are the *grid twins* as seen on this surface. Figure 3B shows two different group directions in the *echelon twins*, and also shows the interchangeability of individual direction within an *echelon* group. This photograph also illustrates the intersection of cubanite bands and *echelon twins*.

the azimuth of the group as a whole (thus the short edge of the individual twin), and the long direction of the individual twin. These two angles are characteristic of the group, and in general, are different from either of the angles in the second possible group on that surface.

The grid twinning and the echelon twinning represent two types which seem to be distinct from one another and not crystallographically equivalent. On the other hand, it may be safely assumed that the two individual directions composing the grid are crystallographically equivalent, and also that the two groups of echelon twins are crystallographically equivalent, on the grounds of similarity.

TABLE II

TABULATED AVERAGE DATA USED IN DETERMINING THE TWIN PLANES IN CHALCOPYRITE

	Angles made by various traces with edge <i>PQ</i>		Angles made by various traces with edge <i>PR</i>	
	plane <i>P</i>	plane <i>Q</i>	plane <i>P</i>	plane <i>R</i>
ECHELON TWINS				
First group				
Group direction	114.5°	131.8°		148.3°
Individual direction	126.2°	65°	38.3°	12.2°
Second group				
Group direction	54.5°	48°		
Individual direction	45°	113°		
GRID TWINS				
First pair	0°	0°	90°	163°
Second pair	0°	0°	90°	77°
Solid angle <i>PQ</i> = 93°				
Solid angle <i>PR</i> = 88°				
Solid angle <i>QR</i> = 90 $\frac{3}{4}$ °				

Both directions of the grid twinning on faces *P* and *Q* happen by pure chance to be mutually parallel to the edge *PQ*. The solution of the planes giving rise to these parallel traces is therefore indeterminate. On face *R*, however, the grid twinning shows in a well developed grid-work.

Each of the four twin directions contained in the echelon groups on face *P* have been accurately correlated with their corresponding directions contained in the echelon groups on face *Q*.

There are thus six distinctly different composition planes, two grids and four echelons. The angles necessary for the stereographic projection of these planes have been measured and averaged values are given in Table II. A stereographic solution has been

carried out for an average pair of trace angles, θ and ϕ , for each of the six composition planes. The solutions of these have been transferred to the composite stereographic projection given in figure 4. The interpretation of the projection will be given in the following section.



FIG. 4. Distribution of cubanite plates and chalcopyrite twin lamellae in chalcopyrite matrix crystal. Original diagram.

ORIENTATION OF THE CHALCOPYRITE CRYSTAL

The chalcopyrite matrix can now be oriented by the following considerations. The processes of gliding and exsolution are centrosymmetrical processes, so they, in themselves introduce symmetry centers into any field in which they may be regarded as entering.¹⁰

¹⁰ Buerger, M. J., Translation-gliding in crystals; *Am. Mineral.*, vol. 15, pp. 52-54, 1930.

The symmetry of chalcopyrite, V^d , must therefore be multiplied by C_4 giving the point group D_4^h , as the symmetry of distribution of exsolution plates and of twin planes.¹¹ The distribution of important axes in this group is as follows. A four-fold axis (coincident with the crystallographic c axis) has two kinds of two-fold axes at

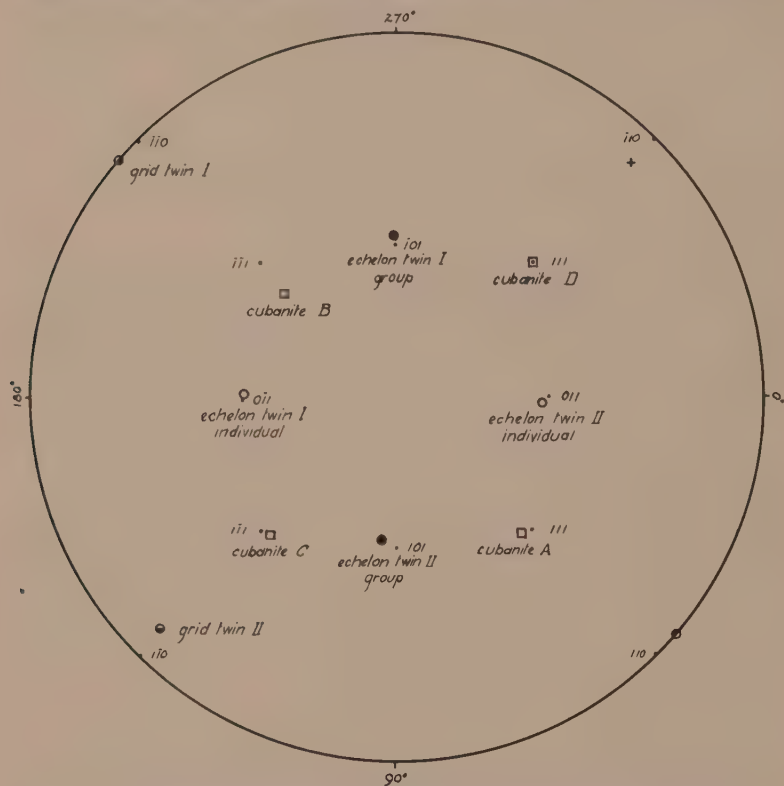


FIG. 5. The distribution of cubanite plates and chalcopyrite twin lamellae in the chalcopyrite matrix crystal, after rotating the projection to conventional crystallographic orientation. The indexed dots give the ideal positions of chalcopyrite poles.

right angles to it. Equivalent two-fold axes of a first kind are mutually at right angles and a second kind of two-fold axes bisect these right angles. The a axes coincide with one of the kinds of two-fold axes, the choice being arbitrarily exercised by the first to de-

¹¹ Reference 10, p. 53. The symbols V^d and C_4 should be transposed in this paper. They have been copied from Roger's paper cited, where the error originally occurs.

scribe the crystal species. This choice may be ascertained for the specific example in question by ascertaining which of the two alternatives gives rational indices with the axes recorded in reference works.

Identification of planes. The poles obtained by the stereographic solutions previously described have been transferred onto a Leitz model of the Wulff rotating net. The resulting composite diagram in the original unrotated position is shown in figure 4.

Considering only the poles of the four cubanite plates, there is at once evident a symmetrical arrangement of these poles about a four-fold axis of symmetry. This applies only to the poles of the cubanite planes. It is apparent that this axis is an important one, and its position gives a hint as to the rotation necessary to orient the chalcopyrite matrix.

After discovering and carrying out the correct rotation the resultant grouping of poles obtained by this rotation is as shown in the composite diagram of figure 5. It is now evident that the four-fold axis applicable to the cubanite planes alone and which now appears along the 0° – 180° axis is coincident with a two-fold axis which may be applied to *all* the planes in this grouping. A second two-fold axis appears along the 90° – 270° axis, two others along the 45° – 225° and 135° – 315° axis, and a four-fold axis appears through the north pole.

The coordinate axes having been fixed, (the *a* axis alternative being kept in mind), the planes of the cubanite segregation, and the twinning in chalcopyrite may now be identified on the stereographic projection by the usual methods. This results in the following determination of indices for the various features studied:

		Number of non-parallel equivalent planes in form
cubanite segregation planes, -	sphenoid {111}	4
grid twin lamellae,	prism {110}	2
echelon twin lamellae	sphenoid {101}	4

It may be noted in passing, that the solutions of the orientations of the cubanite plates *A*, *C*, and *D* are within 3° or less of their ideal sphenoid positions. This is a satisfactory agreement for the type of measurement involved. The cubanite plate *B*, however, is some 10°

from ideal position. This is ascribable to the bent condition observed in this set of plates.

DISCUSSION

Several interesting points develop from the solutions given. In the first place, the surmises with regard to the orientation of segregated cubanite plates in chalcopyrite have been confirmed; the plates develop parallel to the unit sphenoid, $\{111\}$. In addition, two new kinds of twin lamellae have been discovered and determined in chalcopyrite, parallel to $\{110\}$ and $\{101\}$ respectively. Taken together these correspond with pseudo-dodecahedral twinning, yet their appearances are distinguishable. It should be noted that if the recognized,¹² though not very well established, $\{111\}$ lamellae are added to these, all the known twin laws of chalcopyrite are represented by lamellae.

One may inquire whether the new $\{110\}$ and $\{101\}$ lamellae are primary growth phenomena or whether they are secondary twins of some sort. The evidence points rather conclusively to the latter interpretation. If the lamellae were primary, then, since they differ from the crystal proper only in regard to orientation, the cubanite segregations would have had a chance proportional to the volumes involved of precipitating either in the lamellae or in the crystal proper. A very complete study of the cubanite segregation plates has shown that they are related to the crystal proper alone, not to any of the six possible lamellae orientations. This indicates that the appearance of the cubanite plates antedated the appearance of the twins; otherwise some of the cubanite plates would have followed one or more of the twin orientations. Other evidence pointing in the same direction is the following: The cubanite plates end abruptly at chalcopyrite grain boundaries. One deduces from this that the grain boundaries were already present when the cubanite segregated. Now, twin boundaries are simply special cases of grain boundaries. If, therefore, the twin boundaries antedate the cubanite exsolution, the cubanite plates should have the same reason to stop at twin boundaries as at grain boundaries. Actually, however, the cubanite plates cut indiscriminately through twins of both sorts, from which it may be concluded that the twins came into existence *after* the cubanite unmixed. The twinning movement, on the other hand, should disturb the cubanite plates if these were

¹² Reference 6, p. 348.

present first. In confirmation of this, the cubanite plates are frequently in a bent condition. A measure of the bending is gained by noting that the solutions of the orientations of cubanite plates are in error from some 3° average, to 10° maximum, as previously mentioned, due to curvature of the cubanite plates.

Since the cubanite segregation appeared subsequent to the formation of the crystal, this requires the lamellae to be secondary twins. They have arisen, therefore, either from external or internal forces sufficiently intense to cause plastic deformation. The latter forces may be ascribed to volume changes. Either the volume change due to the exsolution of the cubanite, or that due to a possible inversion of the chalcopyrite from a high temperature type,¹³ come up for consideration.

SUMMARY

(1) Cubanite plates segregate on the $\{111\}$ planes of chalcopyrite.

(2) The grid twinning lamellae of chalcopyrite are along the prism $\{110\}$ planes.

(3) The polysynthetic echelon twinning lamellae of chalcopyrite are along the $\{101\}$ planes.

(4) The grid twinning and the echelon twinning correspond to two of the three known twin laws of chalcopyrite established by crystal surface study.

(5) The grid twinning and the echelon twinning are subsequent to the segregation of the cubanite.

(6) Since the twinning is secondary, it has been caused by plastic deformation, and the twin laws stated in (2) and (3) are two new plastic deformation twin laws.

(7) The exsolution of cubanite from chalcopyrite may have been the cause of the stresses which produced the twinning.

¹³ Since writing this the writers have established the existence of two forms of chalcopyrite by a thermal and *x*-ray study. High-chalcopyrite is a disordered structure; low-chalcopyrite is an ordered structure. The onset of order with lowering temperature causes exsolution of atoms present in excess of simple, rational proportions, in the form of cubanite. Details of this study will appear shortly. The theory of the inversion, unmixing, etc., is given in M. J. Buerger, "The temperature-structure-composition behavior of certain crystals"; *Proc. Nat. Acad. Sci.*, vol. 20, July, 1934.

OLIGONITE, A MANGANOSIDERITE FROM LEADVILLE, COLORADO

EVANS B. MAYO AND WM. J. O'LEARY,
(*Contribution from the Departments of Geology and
Chemistry, Cornell University.*)

The specimen, from Leadville, Colorado, described in this paper, came from the Iron Silver Mining Company's Tucson Shaft. The depth at which it was collected is not known.

The appearance of the specimen is shown in figure 1. The darker portion is mainly chalcopyrite and sphalerite in which

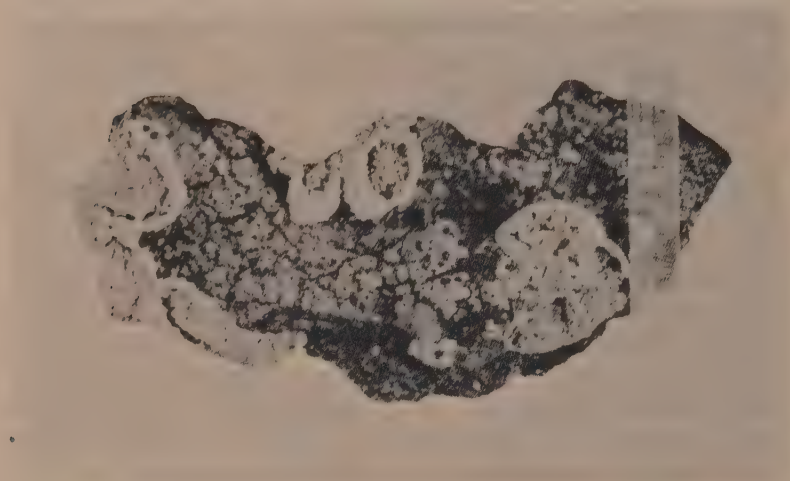


FIG. 1. Photograph of the specimen of oligonite, a manganosiderite, on chalcopyrite, galena, and sphalerite.

hollows have been etched or dissolved, probably by hot vapors, and which has then been encrusted with galena that is now traversed by a network of black sphalerite. The emanations which brought about the solution of blende and chalcopyrite, and which were doubtless also responsible for the deposition of the encrusting galena on the resulting ridge-and-hollow surface, are thought to have issued from small orifices, over which during a closing stage, the remarkable mushroom-like structures, shown in the photograph, were built. The "mushrooms" each consist of an outer shell, about 1/16 inch thick, partially enclosing a bundle of tiny radiat-

ing columns that converge toward the supposed apertures from which the mineralizing solutions escaped. These odd structures are composed of a pale, taffy-colored, slightly iron stained substance which proves to be oligonite, the central member of the rhodochrosite-siderite series. A manganosiderite, apparently almost identical in chemical composition with this one, has already been reported from the zinc ores of Leadville by Loughlin.¹

The carbonate is so finely crystalline that its identification was, at first, a matter of some difficulty. A preliminary spectroscopic examination revealed the presence of iron, manganese, and carbon; the latter was found by chemical methods to be present as carbonate. An x-ray analysis disclosed a crystal structure similar to that of rhodochrosite. Later, tiny rhombohedra were detected in the "mushrooms" with the aid of a binocular microscope, and minute cleavage rhombs were found among the crushed fragments. The material was not homogeneous, but consisted of a mixture of a small proportion of brown, opaque particles in the main bulk of tiny, transparent, colorless rhombs, some of which were coated with the opaque substance. The indices² of these rhombs follow:

$$\epsilon' = 1.695 \pm .003$$

$$\omega = 1.840 \pm .002$$

From these values it is evident that the mineral is optically negative.

The material was crushed in an agate mortar, taking care to avoid any loss of carbon dioxide by prolonged grinding,³ was dried at 105°C., and analyzed as follows:

The carbonate was determined by evolution as CO₂ from sulfuric acid solutions of weighed samples of the mineral, and was absorbed in ascarite, using a train similar to that recommended by Hillebrand and Lundell.⁴ Since most of the iron present was found to be in the ferrous state, the solutions were oxidized with nitric acid and bromine; the excess nitric acid was removed by evaporat-

¹ Loughlin, G. F., The oxidized zinc ores of Leadville, Colorado: *U. S. Geol. Survey, Bull.* **681**, p. 47, 1918.

² The index of the ordinary ray was determined by immersion in a solution of phosphorus in methylene iodide. Details of the preparation and use of this series of liquids will be published later.

³ Johnston, J., and Niggli, P., *Journ. Geol.*, vol. **21**, p. 614, 1913.

⁴ Hillebrand, W. F., and Lundell, G. E. F., *Applied Inorganic Analysis*, p. 623, John Wiley and Sons, New York, 1929.

ing to fumes of SO_3 . The iron was then separated from manganese by means of cupferron, following the procedure of Hillebrand and Lundell,⁵ and was determined as Fe_2O_3 ; from this the total iron content of the mineral was calculated to FeO .

The filtrates were then evaporated with sulfuric and nitric acids to destroy the excess cupferron, and the manganese was determined as pyrophosphate.⁶ Confirming the spectroscopic examination, no lead, zinc, calcium, or magnesium was found by chemical methods. The results of the analyses are listed in the subjoined table. Stated as carbonates, the analysis shows approximately 57 per cent MnCO_3 , 42 per cent FeCO_3 .

TABLE I
ANALYSIS OF OLIGONITE

Sample taken	Grams found			Per cent found			Total
gm	CO_2	Fe_2O_3	$\text{Mn}_2\text{P}_2\text{O}_7$	CO_2	FeO	MnO	
0.2000	0.0757	0.0530	0.1419	37.85	26.09	35.45	99.39
0.5000	0.1899	0.1455	0.3530	37.98	26.18	35.28	99.44

As the table shows, there is a difference of approximately 0.6% unaccounted for, which is assumed to be oxygen; there is also an excess of combined FeO and MnO over the amount required for the CO_2 present. Although the total iron content is reported as FeO , a little of it was in the ferric state; all the manganese is reported as MnO , but some may also have been present as a higher oxide. The heterogeneity of the material, however, accounts for these discrepancies.

The chemical and optical data given above are shown with others in the diagram (Fig. 2). In constructing this figure, only those analyses were chosen which reported no more than one per cent of any substance other than iron and manganese carbonates, and which were accompanied by measured values of ω . Even so, an analysis by N. Sundius,⁷ of a siderite from Ivigtut, Greenland, has been omitted because, if plotted, it would have fallen in the

⁵ Hillebrand, W. F., and Lundell, G. E. F., *loc. cit.*, p. 109.

⁶ Blair, A. A., *The Chemical Analysis of Iron*, p. 106, J. B. Lippincott Co., Philadelphia, 1918.

⁷ Sundius, N., *Optische Bestimmung an FeCO_3 , MnCO_3 , und $\text{CaMg}(\text{CO}_3)_2$* ; *Geol. För. Förh.*, vol. 47, pp. 269-270, 1925. (*Mineral. Abs.*, vol. 3, p. 59, 1926-28.)

cluster of siderite analyses shown in the diagram. The straight diagonal line, marked ω in figure 2, connects the values reported by Ford⁸ for the refractive index of the ordinary ray in the pure end members. The close agreement of the observed value of ω in the oligonite with the theoretical value is confirmatory evidence of the straight line relationship between chemical composition and optical properties throughout the entire series.

FIGURE 2

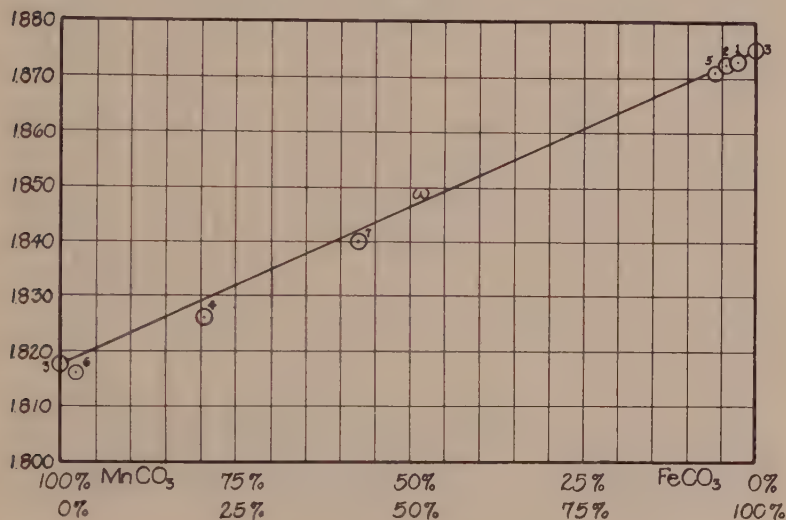


FIG. 2. Measured indices of the ordinary ray in some analyzed members of the rhodochrosite-siderite series.

- (1) "Chalybite" from Cornwall. Hutchinson, *Mineral. Mag.*, vol. 13, p. 209, 1903.
- (2) Siderite from Greenland. Ford, *Trans. Conn. Acad. Arts and Sci.*, vol. 22, p. 243, 1917.
- (3) Pure carbonates. Ford, *ibid.*
- (4) Rhodochrosite (?) from Branchville, Conn. Ford, *ibid.*
- (5) Siderite from Ivigtut, Greenland. Wherry and Larsen, *Jour. Wash. Acad. Sci.*, vol. 7, pp. 365-368, 1917.
- (6) Rhodochrosite from Alma, Colorado. Sundius, *Geol. För. Förh.*, vol. 47, pp. 269-270, 1925. (*Mineral. Abs.*, vol. 3, p. 59, 1926-28.)
- (7) Oligonite from Leadville, Colorado.

The name oligonite was given more than a century ago by A. Breithaupt⁹ to a mineral containing approximately 60% FeCO₃

⁸ Ford, W. E., Studies in the calcite group: *Trans. Conn. Acad. Arts and Sci.*, vol. 22, pp. 211-248, 1917.

⁹ Breithaupt, A., *Journ. f. Chemie u. Physik*, vol. 54, p. 283, 1828.

and 40% MnCO_3 , and the term could well be applied to central members of the rhodochrosite-siderite series, in which the amounts of iron and manganese carbonates do not vary more than 20% from the 50:50 ratio. In 1901, K. Busz¹⁰ proposed the name "manganosphärit" for a mineral practically identical in chemical composition with Breithaupt's material. Unless Busz's term has some special paragenetic significance, its use should be discontinued, because the name adopted in this paper undoubtedly has priority. Both names are applied synonymously by Ford,¹¹ but oligonite alone is preferred by Kraus and Hunt¹² and by the Winchells.¹³

Although analyses of oligonite have been in existence for many years, the Leadville mineral, herein described, appears to be the first for which any optical properties are given.

The best value obtained after numerous attempts to measure the specific gravity of the mineral is 3.722. This result is doubtless somewhat low, because of the porous nature of the material and the consequent difficulty of eliminating included air. In accordance with expectation, the hardness of the mineral proves to be slightly greater than 3.5.

The writers wish to express their appreciation to Professor H. Ries for lending them the specimen and for his constructive criticism of the manuscript, and to Professor Paul F. Kerr, of Columbia University, who kindly furnished the x-ray data.

SUMMARY

Oligonite, the central member of the rhodochrosite-siderite series, has been described, and a definition of the term oligonite has been suggested.

The optical properties of oligonite have been recorded.

The relationship between chemical composition and optical properties has been pointed out in the case of oligonite, and a comparison made with the other members of the rhodochrosite-siderite series.

¹⁰ Busz, K., *Neues Jahrb.*, II, pp. 129-132, 1901.

¹¹ Ford, W. E., Dana's Textbook of Mineralogy, p. 519, John Wiley and Sons, New York, 1932.

¹² Kraus, E. H., and Hunt, W. F., Mineralogy, p. 277, McGraw-Hill, New York, 1928.

¹³ Winchell, N. H., and Winchell, A. N., Elements of Optical Mineralogy, 2, p. 78, John Wiley and Sons, New York, 1927.

CRYSTALLOGRAPHY OF THE URANIUM OXIDES

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The complex suite of oxidation products of uraninite from the Katanga deposits which has been described in recent years, chiefly by Professors Schoep and Buttgenbach, has introduced to mineralogists a great variety of new compounds. The mode of occurrence, however, makes it difficult to isolate these minerals in amounts adequate for satisfactory chemical analysis and, notwithstanding the fairly definite data that exist regarding the crystal form and optical properties of a number of them, the exact chemical nature of several of them is still uncertain. The author has made a small number of crystallographic measurements on minerals of this group which seem, judging by the published descriptions, to be as accurate as those of earlier workers. He has used these measurements in establishing crystal elements which have already been published (9), and it seems proper to place this new data on record. In doing so the results of other studies have been compiled and are here briefly presented.

Schoepite:—Schoepite was first described by Walker (1), who measured and figured a single crystal of prismatic habit. Schoep (2) and (3) also measured crystals and adopted Walker's elements. He notes that the predominant habit, unlike that of Walker's crystal, is tabular parallel to the base. Buttgenbach (4) gave the same forms as Walker but his elements, shown in the table below, differed slightly from those of the earlier writer. Ungemach (5) described several brilliant tabular crystals, one of them very complex with many new forms. In order to simplify the indices of the forms, he suggests doubling the a axis of Walker; his elements are in good agreement with those of the latter. Palache measured several crystals, one of them of excellent quality, and calculated axes agreeing closely with those of Walker and Ungemach. In order to determine the question of the proper choice of the unit form, H. Berman of this laboratory measured the dimensions of the unit cell of schoepite by rotation x -ray photographs. Because of the high absorption of the mineral, the photographs were not as sharp as was expected, but the result was unambiguous and confirmed the choice of Walker, which is here used.

Becquerelite:—Becquerelite was first described by Schoep and his observations are expanded in his later papers (2) and (3).

TABLE I. AXIAL ELEMENTS OF SCHOEPITE

	<i>a</i>	<i>c</i>
Walker (1)	0.426	0.875
Schoep (3)	0.426	0.875
Buttgenbach (4)	0.42757	0.89986
Ungemach (5)	0.4262	0.8744
Palache (unpublished)	0.4253	0.8741
Mean of Walker, Ungemach & Palache	0.4258	0.8745

TABLE II. ANGLES AND FORMS OF SCHOEPITE AND THEIR OBSERVERS

$$a=0.4258 \quad p_0=2.0538$$

$$c=0.8745 \quad q_0=0.8745$$

			Walker	Buttgen- bach	Schoep	Palache	Unge- mach
	ϕ	ρ					
1 <i>c</i>	001	0°00'	x	x	x	x	x
2 <i>b</i>	010	0°00'	x	x	x	x	x
3 <i>a</i>	100	90°00'	x	x	x	x	x
4 <i>n</i>	120	49°35'					x
5 <i>m</i>	110	66°56'	x	x	x	x	x
6 <i>g</i>	015	0°00'					x
7 <i>h</i>	014	0°00'					x
8 <i>i</i>	027	0°00'					x
9 <i>k</i>	012	0°00'					x
10 <i>z</i>	023	0°00'					x
11 <i>d</i>	011	0°00'	x	x	x	x	x
12 <i>f</i>	021	0°00'	x	x	x	x	x
13 <i>e</i>	041	0°00'	x	x			x
14 <i>x</i>	104	90°00'	x	x			x
15 <i>r</i>	113	66°56'					x
16 <i>s</i>	112	66°56'				x	x
17 <i>p</i>	111	66°56'	x	x	x	x	x
18 <i>q</i>	124	49°35'	x	x	x	x	x
19 <i>o</i>	122	49°35'	x	x	x	x	x
20 <i>u</i>	144	30°25'				x	x
21 <i>v</i>	142	30°25'					x
22 <i>t</i>	121	49°35'					x
23 <i>w</i>	342	60°25'					x

Buttgenbach (4) gives the same data but adds a number of forms. Ungemach (5) has also measured and figured crystals and added largely to the form series. Tabulated with these results below are the data obtained by Palache on five crystals of good quality.

TABLE III. AXIAL ELEMENTS OF BECQUERELITE

	<i>a</i>	<i>c</i>
Schoep (2)	0.5722	0.6173
Schoep (3)	0.5537	0.5938
Schoep (6)	0.5537	0.5938
Buttgenbach (4)	0.5537	0.5938
Ungemach (5)	0.5591	0.6056
Palache (unpub.)	0.55905	0.6044
Mean of last two	0.5591	0.6050

In order to bring about closer similarity to the elements of schoepite the *c* axis is doubled and the elements of becquerelite adopted in this paper are therefore:—

$$a = 0.5591 \quad p_0 = 2.1642$$

$$c = 1.2100 \quad q_0 = 1.2100$$

The five crystals measured by the author were tabular parallel to the base and elongated parallel to *b*. The data on which are based the forms observed by him and not by others are as follows:—

		ϕ	ρ	
<i>a</i>	100	90°00'	90°00'	2 faces, good quality
<i>n</i>	130	30°50'	90°00'	2 faces, fair quality
<i>h</i>	051	0°00'	80°13'	1 face, poor quality
<i>j</i>	308	90°00'	38°55'	1 face, poor quality
		89°34'	38°22'	1 face, poor quality
<i>r</i>	332	60°39'	74°28'	1 face, good quality
<i>s</i>	221	60°52'	78°23'	line face, fair quality
		60°24'	78°55'	line face, fair quality
<i>y</i>	124	41°40'	39°45'	1 face, poor quality

“*Mineral X*”:—A mineral occurring at Great Bear Lake, Canada, with other oxidation products of pitchblende and probably a lead-free oxide of uranium, was described by Palache and Berman (10). The elements of this mineral are intermediate between those of schoepite and becquerelite. Like them it is platy parallel to a direction of perfect cleavage which is taken as basal. The analysis, made on very little material which was impure, was unsatisfactory

TABLE IV. ANGLES AND FORMS OF BECQUERELITE AND THEIR OBSERVERS

$$a=0.5591$$

$$p_0=2.1642$$

$$c=1.2100$$

$$q_0=1.2100$$

					Schoep	Buttgen- bach	Unge- mach	Palache
		ϕ	ρ					
1	<i>c</i>	001	0°00'	0°00'	x	x	x	x
2	<i>b</i>	010	0°00'	90°00'	x	x	x	x
3	<i>a</i>	100	90°00'	90°00'			x	x
4	<i>n</i>	130	30°48'	90°00'			x	x
5	<i>m</i>	110	60°47½'	90°00'	x	x	x	x
6	<i>e</i>	011	0°00'	50°25½'	x	x	x	x
7	<i>g</i>	031	0°00'	74°36'		x		
8	<i>z</i>	041	0°00'	78°19½'			x	
9	<i>h</i>	051	0°00'	80°37'			x	x
10	<i>i</i>	106	90°00'	19°50'		x		x
11	<i>f</i>	104	90°00'	28°25'	x	x	x	x
12	<i>k</i>	3.0.10	90°00'	33°00'	x	x		
13	<i>A</i>	103	90°00'	35°48½'		x	x	
14	<i>j</i>	308	90°00'	39°03½'			x	x
15	<i>l</i>	7.0.18	90°00'	40°05'			x	
16	<i>q</i>	205	90°00'	40°53'			x	
17	<i>t</i>	5.0.12	90°00'	42°02½'			x	
18	<i>u</i>	7.0.16	90°00'	43°26'			x	
19	<i>d</i>	102	90°00'	47°15½'	x	x	x	x
20	<i>v</i>	508	90°00'	53°31½'			x	
21	<i>o</i>	112	60°47½'	51°06½'			x	
22	<i>p</i>	111	60°47½'	68°02'		x	x	
23	<i>r</i>	332	60°47½'	74°57'				x
24	<i>s</i>	221	60°47½'	78°36'				x
25	<i>y</i>	124	41°48½'	39°04'				x
26	<i>x</i>	122	41°48½'	58°22'			x	x
27	<i>w</i>	322	69°33½'	73°54'		x	x	x

but seems to indicate the composition $\text{UO}_3 \cdot 2\text{H}_2\text{O}$. The elements, forms and angles are as follows:

	$a=0.490$	$p_0=2.12$	
	$c=1.04$	$q_0=1.04$	
		ϕ	ρ
n	120	$45^\circ 35'$	$90^\circ 00'$
d	011	$0^\circ 00'$	$46^\circ 11'$
f	021	$0^\circ 00'$	$64^\circ 22'$
p	111	$63^\circ 54'$	$67^\circ 07'$

Fourmarierite.—Fourmarierite was first described by Buttgenbach (8) and nothing has been added to his description of the crystal form. As originally oriented the cleavage was made macro-pinacoidal. By interchanging a and c , making the cleavage basal, a closer relation to schoepite appears, and for this paper this change has been made. The elements of Buttgenbach, recalculated to this position are:—

$a=0.4056$	$p_0=2.1775$
$c=0.8832$	$q_0=0.8832$

The forms become:—

Buttgenbach		New Position		ϕ	ρ
h'	100	c	001	$0^\circ 00'$	$0^\circ 00'$
$m_{\frac{1}{2}}$	110	d	011	$0^\circ 00'$	$41^\circ 27'$
b	111	s	122	$50^\circ 57'$	$54^\circ 30'$

Ianthinite.—Ianthinite was first described by Schoep (6) and his data for the crystal form remain the sole source of information. The cleavage is taken as the macropinacoid and the habit is tabular parallel to this form. Schoep's elements, given below, were calculated from the angle ρ of (011) and the angle ϕ of (130). However, by changing the position so that a (Schoep) becomes c , and b (Schoep) becomes a , both cleavage and optical orientation fall into parallelism with those of preceding minerals. This new orientation is adopted here and the result is shown in the table.

ELEMENTS OF IANTHINITE

Schoep		Palache (new position)	
$a=0.8646$	$p_0=0.7713$	$a=0.4998$	$p_0=2.5938$
$c=0.6669$	$q_0=0.6669$	$c=1.2964$	$q_0=1.2964$

FORMS AND ANGLES OF IANTHINITE

Schoep (observed)				(Observed angles transformed to new position)				Calculated	
		ϕ	ρ			ϕ	ρ	ϕ	ρ
a	(100)	$90^\circ 00'$	$90^\circ 00'$	c	001	—	—	—	—
*g	(130)	$21^\circ 05'$	$90^\circ 00'$	g	101	$90^\circ 00'$	$68^\circ 55'$	$90^\circ 00'$	$68^\circ 55'$
m	(110)	$49^\circ 09'$	$90^\circ 00'$	m	103	$90^\circ 00'$	$40^\circ 48\frac{1}{2}'$	$90^\circ 00'$	$40^\circ 51'$
*f	(011)	$0^\circ 00'$	$33^\circ 42'$	f	130	$33^\circ 42'$	$90^\circ 00'$	$33^\circ 42'$	$90^\circ 00'$
d	(101)	$90^\circ 00'$	$37^\circ 41'$	d	011	$0^\circ 00'$	$52^\circ 19'$	$0^\circ 00'$	$52^\circ 21'$

Curite.—Curite was first described by Schoep (6) and little has since been added to our knowledge of its crystal form. The simple crystals are minute and rather poor, and there is a cleavage, determined by Berman to be parallel to the direction taken as the macropinacoid. Two crystals were measured in this laboratory and their angles were averaged with those of Schoep for determination of elements.

	ϕ	ρ
Schoep, five crystals average for (111)	$46^{\circ}18\frac{1}{2}'$	$43^{\circ}25'$
Palache and Berman, two crystals average for (111)	$45^{\circ}52'$	$43^{\circ}07'$
Weighted mean for (111)	$46^{\circ}11'$	$43^{\circ}20'$

The elements are:—

$$\begin{aligned} a &= 0.9595 & p_0 &= 0.6808 \\ c &= 0.6532 & q_0 &= 0.6532 \end{aligned}$$

Attempts to so transform the position of curite that its elements more nearly resembled those of other members of this series were unsuccessful.

General Relations.—The peculiar relations of these six minerals are unclear and must remain so until more is known of their chemical nature. All are orthorhombic and a general similarity exists in their cleavage and their crystallographic elements. To bring this out more clearly they are tabulated below. The column showing optical orientation has been prepared by Mr. Berman after the study of measured crystals.

TABLE V. SOME PROPERTIES OF THE URANIUM OXIDES

Formula	Optical Orientation	Cleavage	a	$c = q_0$	p_0
Schoepite $3\text{UO}_3 \cdot 7\text{H}_2\text{O}$	$X = c \ Y = b$	001	0.4258	0.8745	2.0538
"Mineral X" $\text{UO}_3 \cdot 2\text{H}_2\text{O} (?)$	$X = c \ Y = b$	001	0.490	1.04	2.12
Becquerelite $4\text{UO}_3 \cdot 7\text{H}_2\text{O}$	$X = c \ Y = b$	001	0.5591	1.2100	2.1642
Ianthinite $2\text{UO}_3 \cdot 7\text{H}_2\text{O}$	$X = c \ Y = b$	001	0.4998	1.2964	2.5938
Fourmarierite $\text{PbO} \cdot 4\text{UO}_3 \cdot 5\text{H}_2\text{O}$	$X = c \ Y = a$	001	0.4056	0.8832	2.1775
Curite $2\text{PbO} \cdot 5\text{UO}_3 \cdot 4\text{H}_2\text{O}$	$Z = c \ Y = a$	100	0.9595	0.6532	0.6808

The formulae assigned to schoepite and becquerelite are those of Schoep's latest paper (7). They are based on water determinations alone, made on microchemical samples, and are certainly open to question. The mean values of all the water determinations published on both minerals certainly indicate their probable identity of composition with the formula $\text{UO}_3 \cdot 2\text{H}_2\text{O}$.

It will be seen that there is a close similarity in the elements of five of these six minerals, curite alone being widely different. This similarity is closest between schoepite and fourmarierite, amounting almost to identity of form, but their optical orientation and chemical composition are different. If the values of $p_0 (= c/a)$ of the first four are compared, it will be seen that they increase more or less regularly from schoepite onward. When structural studies have been made, some explanation of this peculiar set of relations may be discovered, but at present they simply have to be termed anomalous.

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SELECTIVE INCRUSTATION OF CRYSTAL FORMS

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SUMMARY

A number of instances of crystals which have had a particular form, or group of forms, covered by a super-deposited mineral while other forms on the crystal were not incrustated, have been described in the literature. A search of the mineral collection of the American Museum of Natural History has revealed further instances of selectivity in incrustation of this kind. The placing of the super-deposited mineral can be referred to the adsorption processes operating at a crystal-solution interface, the selectivity being due to the varying adsorptive power of the different forms as their structural makeup varies with their crystallographic orientation. Two general types may be recognized on the basis of the mode of deposition of the incrusting mineral: (a) a type represented by crystals which have selectively adsorbed during, or after completion of their growth, colloidal particles of another substance, and (b) a type resulting from the selective adsorption of a substance from true solution on the forms of a crystal which has completed its growth, followed by its crystallization on the form or forms in question.

DESCRIPTION OF SPECIMENS

One of the clearest examples of selectivity in deposition on crystal forms has been described by Haworth,¹ who found calcite crystals from Potosi, Missouri, showing the scalenohedron ($13\bar{4}1$) modified by faces of ($21\bar{3}1$) and ($02\bar{2}1$) (?), with a surface film of amber colored ferric oxide (probably limonite) on the modifying form ($21\bar{3}1$) and not on the others. As the film became thicker with increasing deposition, as shown on other specimens, it is noted that the rhombohedron ($02\bar{2}1$) was covered next, leaving only ($13\bar{4}1$) clean, and that the limonite covered the whole crystal only "after it became so abundant that the molecular force of the calcite could no longer control it." Haworth also speaks of the "molecular control exerted by the calcite" and of "the controlling force a crystal has over the molecules of a . . . [substance depositing] . . . on it." A similar instance of selectivity has been described on a calcite crystal from a hematite deposit in the Glenariff Valley, Co. Antrim, Ireland.² The crystal is composed largely of the scalenohedron ($13\cdot11\cdot24\cdot2$) with small modifying faces of the rhombohedrons ($10\bar{1}1$), ($02\bar{2}1$) and ($40\bar{4}1$). Part of the scalenohedral faces are overgrown by a thin layer of calcite showing oscillatory faces of ($13\bar{4}1$) and ($16\bar{7}1$). The form ($02\bar{2}1$) is selectively covered by a

¹ Haworth, E., *Proc. Iowa Acad. Sci.*, vol. 1, Pt. 2, p. 35, 1892.

² O'Reilly, J. P., *Proc. Royal Dublin Soc.*, vol. 4, p. 43, 1885. Plate II.

strongly marked film of iron oxide and its faces appear as red bands or stripes on the crystal. What is apparently another instance of this kind has been described by Farrington³ on a calcite crystal from the Crystal Palace Mine, Central City, Missouri. The crystal is formed largely of (0553) and (0112) with the modifying forms (4041) and (2131). All of these, with the exception of (0112), are stated to be coated with a thin firmly adhering layer of chocolate brown iron oxide. No specific remark is made of the selectivity.

Cook and Kraus⁴ have described a datolite crystal from Great Notch, N. J., with the forms (102), (110), (012) (011), (100), (111), and (112) in which the first four forms cited are incrustated by a thin layer of stilbite (?) and the other forms left unincrustated.

An instance has been mentioned by Miers⁵ where galena crystals incrust in parallel position the prism faces of a bournonite crystal but do not incrust the base. The habit of the galena is not stated. A specimen showing the reverse of this—bournonite selectively incrusting the forms of galena—has been described by Hintze.⁶ Here a galena cubo-octahedron from Przibram, Bohemia, has its cube faces heavily coated by small crystals of bournonite, oriented to the galena, while on the octahedral faces the incrustation is almost lacking.

A tendency for albite to form parallel growths on only certain forms of orthoclase crystals, particularly the prism (110), has been noted by many observers.⁷ Goodchild briefly ascribed the selectivity in this case to a difference in "surface tension" of the orthoclase faces.⁸

The oriented growths of quartz on calcite crystals also show a preference for deposition on certain of the several crystal forms that may be available.⁹ These forms are usually (0112) or (1011);

³ Farrington, O. C., *Field Columbian Mus., Geol. Ser.*, vol. 3, p. 141, 1908, Pl. XLVIII, Fig. 1.

⁴ Cook, C. W., and Kraus, E. H., *Amer. Jour. Sci.*, ser. 4, vol. 39, p. 643, 1915 with fig.

⁵ Miers, H. A., *Min. Mag.*, vol. 11, p. 268, 1897.

⁶ Hintze, C., *Zeit. Kryst.*, vol. 11, p. 606, 1886, with fig.

⁷ See in particular Mügge (*Neues Jahrb. Beil.-Bd.*, vol. 16, p. 432, 1903), who cites a number of instances; also G. Rose, *Pogg. Annalen*, vol. 80, p. 123, 1850, and A. Knop, *Neues Jahrb.*, p. 53, 1858. Goldschmidt's *Atlas der Krystallformen* shows many examples (Band 3: Tafel 172, fig. 73; T. 176, f. 124; T. 178, f. 153, 161; T. 183, f. 231, 242; T. 187, f. 301).

⁸ Goodchild, J. G., *Proc. Royal Soc. Edinburgh*, vol. 24, p. 324, 1902.

⁹ Mügge, O., *op. cit.*, pp. 370-3.

however, Solly¹⁰ has described a clear-cut case where the quartz (unoriented) coats $(21\bar{3}1)$ of a crystal composed of $(21\bar{3}1)$ and $(10\bar{1}1)$ and leaves the latter form clean.

Two rather doubtful instances of pyrite selectively incrusting the forms of calcite have been described. Young¹¹ found calcite crystals from the Rand, South Africa, apparently consisting of a scalenohedron terminated by a steep rhombohedron, no definite description being given, in which the outer zone of the calcite contains innumerable minute crystals of pyrite which give the calcite a greenish tint. The pyrite has "very evidently been precipitated by preference on edges and corners of the crystals. . . . It is quite common to find the rhombohedral terminations wholly or partially covered by an aggregation of pyrite crystals." J. D. Dana¹² described calcite crystals from Rossie, N. Y., showing $(10\bar{1}1)$ modified by (0001) , in which the basal plane is stated to have been incrustated by pyrite and then overgrown, in part or completely, by later growth of the crystal.

SPECIMENS IN THE AMERICAN MUSEUM

Many additional examples of the selective incrustation of crystal forms are contained in the collection of the American Museum of Natural History.¹³ Some of the most interesting of these specimens will be briefly described under the following headings.

QUARTZ

A number of instances were observed in which quartz crystals had one of their terminating rhombohedrons—in all but one instance the positive $r(10\bar{1}1)$ rhombohedron—selectively filmed by another substance. A suite of 15 specimens from West Paterson, N. J. (grouped under cat. nos. 19657, 17549, 12712) presents drusy surfaces of small (2–5 mm.) colorless or faintly amethystine quartz crystals associated with calcite and zeolites. Hundreds of quartz crystals are shown. Each of the crystals has the surface of the positive rhombohedron covered by a dense film of bright red hematite particles while the negative rhombohedron is not filmed. The film on many of the crystals can be rubbed off by using pres-

¹⁰ Solly, R. H., *Min. Mag.*, vol. 6, p. 120, 1885.

¹¹ Young, R. B., *Trans. Geol. Soc. South Africa*, vol. 12, p. 93, 1910.

¹² Dana, J. D., *Amer. Jour. Sci.*, ser. 1, vol. 46, p. 33, 1844, fig. 2.

¹³ More detailed papers describing this material are in preparation.

sure but on a few it is covered over by a later deposition of quartz. The quartz surface revealed by removal of the film is brilliantly reflecting and perfectly smooth. The prism faces of the crystals are only thinly filmed by the hematite and the deposition is plainly greatest along the prism edges (Fig. 1). On a number of the crystals the prism faces are not filmed at all. Twins in which the crystals have parallel axes and faces (twin plane $(10\bar{1}0)$) were observed

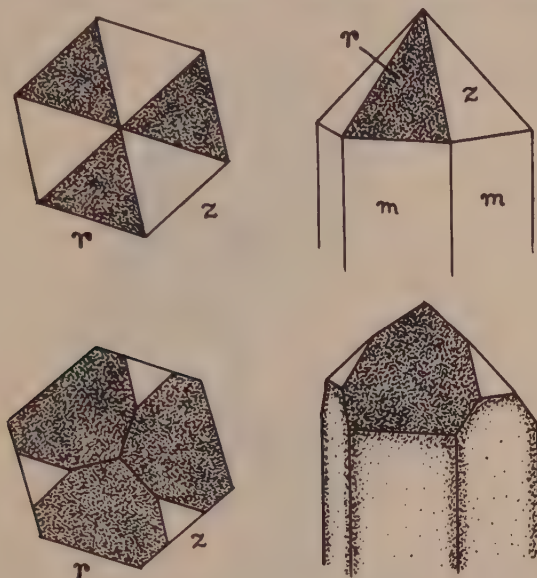


FIG. 1. Hematite (stippled) selectively filming $r(10\bar{1}1)$ of quartz. West Paterson, N. J. Amer. Mus. Nat. Hist., cat. no.'s 19657, 12712, 17549.

in which small irregularly bounded areas of $r(10\bar{1}1)$ were inserted in $z(01\bar{1}1)$, in twin position, and were filmed over by the hematite while the remainder of the $z(01\bar{1}1)$ face remained clean. Areas of z twinned into r were also observed and these were free from deposition.

A second type of deposition on quartz, also with selectivity between the terminating rhombohedrons, is shown by two specimens from the pegmatite occurrences of North Carolina. One of these, from Burke Co., N. C. (cat. no. 3985), shows a 13 cm. quartz crystal which has included on the faces of the positive rhombohedron, during the last stages of its growth, an amount of colloidal clay material. The clay charged zone is cream-white in color and

opaque, with an enameled appearance, and is about 1 mm. thick. The faces of the negative rhombohedron are the ordinary transparent quartz of the crystal. The clay substance is uniformly present over the entire surface of the faces of the positive rhombohedron, with the exception of irregular areas of the negative rhombohedron inserted in twin position which are free from deposition (Fig. 2). The crystal is right-handed and shows small faces of $s(11\bar{2}1)$ and $x(51\bar{6}1)$ and an unidentified negative rhombohedron, below z , all of which are filmed over. A second specimen, from Alexander Co., N. C. (cat. no. 3951), presents an appearance

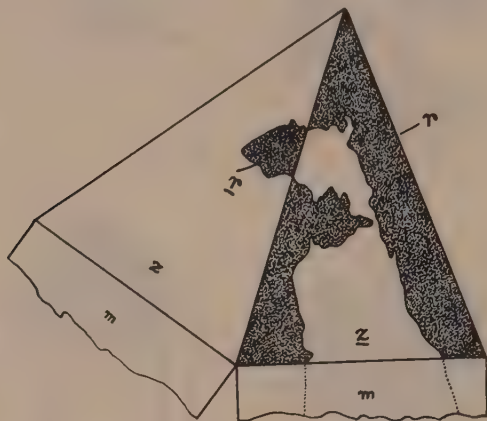


FIG. 2. Tracing of a single twinned insert (tw. pl. $(10\bar{1}0)$) of z in r and \bar{r} in z showing deposition of the clay substance (stippled). Burke Co., N. C. Amer. Mus. Nat. Hist., cat. no. 3985. $2/3$ natural size.

similar to the preceding specimen but differs in that it is the negative rhombohedron, judging from the relative size of the faces, that is filmed over. No readily determinable modifying forms or surface markings were observed to distinguish the forms and a further examination of this specimen is deferred to a later paper.

CALCITE

A group of calcite specimens from Guanajuato, Mexico (cat. nos. 6735, 6672, 6650), show large crystals of complex habit which are covered over by a thin continuous crust of dolomite not tightly adherent to the calcite surface. Removal of this crust reveals the original surface of the calcite to have been selectively covered by a very thin micro-crystalline layer of substance, dead-white in color.

Specimen 6735 shows a 5 cm. crystal with the forms $v(21\bar{3}1)$, $l(04\bar{4}5)$, $h(03\bar{3}2)$, $f(02\bar{2}1)$, $s(05\bar{5}1)$, $\beta(24\bar{6}1)$ and $r:(35\bar{8}1)$, identified by contact measurements, of which the first three forms cited are incrustated and the last four not incrustated (Fig. 3). The incrustation is absent from an area about .2 mm. wide along the edges of the incrustated forms. The nature of the incrustation made its identification difficult but it is definitely either dolomite or calcite. Ara-

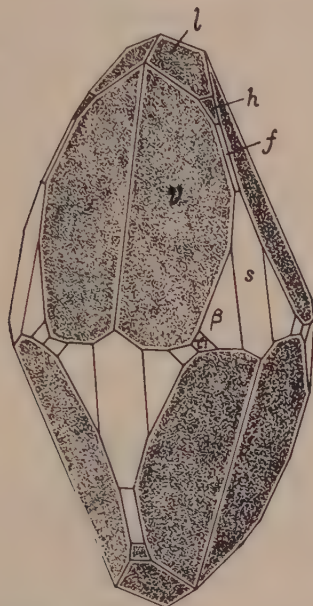


FIG. 3. Dolomite (?) (stippled) selectively incrusting the forms of a calcite crystal from Guanajuato, Mexico. Amer. Mus. Nat. Hist., cat. no. 6735.

gonite was identified as a uniform crust on other calcite specimens from this locality, without the association with dolomite, and it is possible that the incrustation may represent aragonite altered by paramorphism to calcite through the influence of the dolomite deposition.

A second type of selectivity on calcite is shown by a group of crystals from Rossie, N. Y. (cat. no. 7017) which consist of $v(21\bar{3}1)$ with $r(10\bar{1}1)$. The latter form is covered by a film of goethite (?), golden brown in color, and broken into minute flakes, which gives it a spangled appearance. This may have resulted from the desiccation of an iron oxide gel layer originally covering the surface. The

goethite was deposited while the crystal was still growing as a rim of calcite, raised very slightly above the level of the goethite film, extends around the edges of the terminating rhombohedron (Fig. 4). This calcite does not extend over the goethite and the latter has evidently prevented the deposition of calcite over the area covered by it.

GALENA

Three instances were noted where galena cubo-octahedrons were selectively incrustated by other minerals. One specimen, from Gonderbach, Nassau, Germany, (cat. no. 870), shows about 40 small

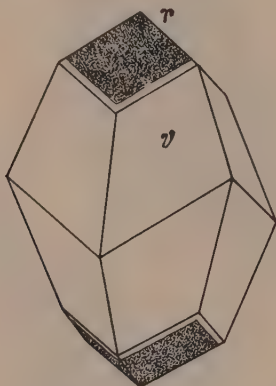


FIG. 4. Goethite (?) (stippled) selectively filming the forms of a calcite crystal. Rossie, N. Y. Amer. Mus. Nat. Hist., cat. no. 7017.

(up to 1 mm.) galena cubo-octahedrons scattered over a matrix of drusy quartz. On all but three or four of these crystals the cube faces are evenly and entirely covered by a thin granular layer of pyrite, while the octahedral faces have not received a trace of deposition. The remaining crystals are lightly incrustated by pyrite in a narrow area paralleling the cube edges while the interior of the cube face is clean. The crystals are notable for the brilliant and untarnished appearance of the faces and the sharpness of the edges and differ in these respects from most galena crystals.

A second specimen, from Laasphe, Westphalia (cat. no. 891), shows a number of galena cubo-octahedrons, ranging in size from 1 to 3 cm., with the octahedral faces incrustated by a thin crust of chalcopryite while the cube faces are clean. On the smaller galena crystals the incrustation is more intense and more uniform, form-

ing a continuous dull rough surface; on the (111) faces of the larger crystals the incrustation is in scattered areas and forms in part irregular thread-like aggregates. Of the forty-odd crystals on the specimen about a dozen are free from incrustation or show only an incipient incrustation in the form of a narrow ridge of chalcopyrite on the octahedral edges. With increasing deposition the incrustation gradually extends into the octahedral faces. The cube faces are rather small and elongated and show the ordinary dull tarnish of the species.

Another instance of chalcopyrite selectively incrusting (111) of galena cubo-octahedrons was found on a specimen from Aini, Japan (cat. no. 18373). This specimen presents cubes, up to 4 cm. in size, with small octahedral modifications. The latter are plated by a smooth brightly reflecting layer of chalcopyrite similar to the chalcopyrite films sometimes seen on sphalerite and tetrahedrite crystals. It was noted on this and on the preceding specimen that the edges of some of the larger crystals had been slightly rounded or scalloped by solution before the formation of the incrustation.

ORIGIN OF THE SELECTIVITY GENERAL THEORY

The investigation of adsorption at crystal-solution interfaces has lagged somewhat behind that of the other kinds of interface and it is only in recent years, with the increase in knowledge of crystal structure, that this part of the field has seen any definite advance. While a complete knowledge of the factors that influence adsorption at this kind of interface is still far from being realized the primary cause of the phenomenon is firmly established in theory. This refers adsorption on a crystal surface to the existence of an open field of force at the surface of the crystal lattice, the field varying in intensity with the crystallographic orientation of the surface plane and its structural makeup, and the interaction of this field with the surface fields of molecules, ions, colloidal particles, etc., which may come into contact with the surface. The interior of the lattice is electrically neutral as the force field of each lattice unit is saturated by the surrounding units, however, the removal of certain lattice units from the interior of the structure may open up the force field in the interior and give it a holding power for foreign substances. The adsorption of gases, silver salts, alcohol, etc., by dehydrated zeolites has been suggested to be of this nature,

the adsorbate diffusing into the interior of the crystal through relatively open channels in the structure.

The relation between the adsorption of ions or molecules on a crystalline surface and crystal growth can be brought out in a general way by drawing the distinction that the holding of lattice units similar to those forming the crystal by the surface forces constitutes growth, and of dissimilar lattice units is adsorption. Both adsorption and growth depend on the size, shape, structure and magnitude of the force fields of the accreting substance and the crystal surface and their interaction. If these factors are identical for both adsorbate and adsorbent, permitting an exact dovetailing, we get growth, the velocity varying in different crystallographic directions and varying with the external conditions; as the factors diverge we pass from pure growth through isomorphism to adsorption proper, the adsorption finally becoming restricted to some particular plane on which there is a minimum coincidence of the factors. Beyond this, as the factors diverge further, as in the case of a crystal growing from a solution containing an amount of a very dissimilar foreign substance, there will be no adsorption, although the foreign substance by changing the internal condition of the solution may affect the growth.

The selective nature of adsorption on the planes of a crystal is known experimentally largely from indirect evidence afforded by the modification of the habit of artificially grown crystals through the adsorption of foreign substances present in small amounts in the crystallizing solution. The treatment of this phenomenon as due to adsorption dates from the work of Marc¹⁴; recent investigations include those of Buckley,¹⁵ Saylor,¹⁶ Walcott,¹⁷ Marc and co-workers,^{18,19} Gaubert,²⁰ Wherry,²¹ and France and co-workers. In the

¹⁴ Marc, R., *Zeit. physik. Chem.*, vol. **81**, p. 641, 1912; *Zeit. Elektrochem.*, vol. **20**, p. 515, 1914. F. Haber in a note in the latter paper is the first to suggest that adsorption is due to open valencies on the surface of a crystal.

¹⁵ Buckley, H. E., *Zeit. Kryst.*, vol. **73**, p. 443, 1930; vol. **75**, p. 15, 1930; vol. **76**, p. 147, 1930; vol. **78**, p. 412, 1931; vol. **80**, p. 238, 1931; vol. **81**, p. 157, 1932; vol. **82**, p. 285, 1932.

¹⁶ Saylor, C. H., *Jour. Phys. Chem.*, vol. **32**, p. 1441, 1928; *Colloid Symp. Ann.*, vol. **5**, p. 49, 1928.

¹⁷ Walcott, A. J., *Amer. Min.*, vol. **11**, pp. 221, 239, 1926.

¹⁸ Marc, R., and Ritzel, A., *Zeit. physik. Chem.*, vol. **76**, p. 584, 1911.

¹⁹ Marc, R., and Wenk, W., *Zeit. physik. Chem.*, vol. **68**, p. 104, 1910.

²⁰ Gaubert, P., *Ann. Rept. Smithsonian Inst.*, p. 271, 1909-10; *Bull. soc. min. franc.*, vol. **38**, 149, 1915; *Compt. rend.*, vol. **180**, p. 378, 1925; *ibid.*, vol. **190**, p. 1230, 1930.

older literature reference should be made to Beudant,²² von Hauer,²³ and Retgers.²⁴ The habit change in such cases is due to the modification of the relative growth rates of the various forms by a selective adsorption on one (or several) of them. In the well known case of sodium chloride with urea as an additive the octahedral habit is due to a selective adsorption of the urea on (111) which slows the growth velocity of this form relative to (100), ordinarily the slower growing form, and allows it to develop as the dominant habit.²⁵ The retardation of the growth velocity by the adsorption is due to the adsorbed substance acting as a protecting blanket and slowing or preventing the normal accretion on the surface.

More obvious evidence of selectivity is offered by crystals grown from solutions containing a dye which have adsorbed the dye on certain planes yielding a crystal with colored zones, as studied particularly by France and co-workers,²⁶ and, earlier, by Milligan.²⁷ The adsorption is usually accompanied by a change in habit, the dye adsorbing forms extending their boundaries at the expense of the faster growing forms. The hour-glass augites found in igneous rocks are also believed to owe their color distribution to the selective adsorption of a colored titania-rich molecule, or TiO_2 , on certain crystal forms.²⁸

In the adsorption of dyes by a growing crystal France²⁹ cites as controlling factors in the adsorption the force field of the crystal surface, the interionic distances, and the presence and distribution of polar groups in the dye molecule. In a typical example, the adsorption of diamine sky blue by potassium alum, the dye is selec-

²¹ Wherry, E. T., *Amer. Min.*, vol. 6, p. 39, 1921; vol. 9, 45, 1924.

²² Beudant, F. S., *Traité elem. de Min.*, 2nd ed., vol. 1, p. 189, 1830.

²³ Von Hauer, K., *Verh. der k. k. Geol. Reichsanst. Wien*, 1877, pp. 45, 57, 75, 90, 162, 296; 1878, pp. 185, 315; 1880, pp. 20, 181 (abstr. in *Min. Mag.*, vol. 1, p. 243, 1877; vol. 2, pp. 95, 241, 1879; vol. 4, p. 73, 1882.

²⁴ Retgers, J. W., *Zeit. physik. Chem.*, vol. 9, p. 267, 1892; *ibid.*, vol. 12, p. 600, 1893; *Zeit. Kryst.*, vol. 25, p. 512, 1896.

²⁵ Gille, F., and Spangenberg, K., *Zeit. Kryst.*, vol. 65, p. 204, 1927.

²⁶ France, W. G., *Colloid Sympos. Ann.*, vol. 7, p. 59, 1930. Foote, F. C., and France, W. G., *Jour. Phys. Chem.*, vol. 34, p. 2236, 1930. Lash, M. T., and France, W. G., *Jour. Phys. Chém.*, vol. 34, p. 724, 1930. Bennet, G. W., and France, W. G., *Jour. Amer. Ceramic Soc.*, vol. 11, p. 571, 1928.

²⁷ Milligan, A. G., *Jour. Phys. Chem.*, vol. 33, p. 1363, 1929.

²⁸ Scott, A., *Min. Mag.*, vol. 17, p. 104, 1914.

²⁹ France, W. G., *op. cit.*

tively adsorbed on (100), leaving (111) uncolored, and the habit changes from the ordinary octahedral one to cubic. The (100) form has the more intense surface field, and is the stronger adsorbing, since the lattice units composing the surface are either all positive or all negative, in alternate layers, while the (111) form is of the checker-board kind, composed of both positive and negative units, and its surface field is lowered by partial polarization. With halite this is reversed, the (100) form being of the checker-board kind (i.e., with both Na^+ and Cl^- on the surface) while (111) is of the all-alike kind (i.e., with either all Na^+ or all Cl^- in alternate layers); the ordinary habit is determined by the low field (100) form but in the presence of many foreign substances adsorption takes places on the high field (111) form, slowing its growth velocity below that of (100) and allowing it to develop as the dominant habit. Buckley and Cocker³⁰ in recent work on the adsorption of dyes by growing crystals find that the adsorption may be many times greater than that of an inorganic ion. The seat of the attaching power in the dye molecule is stated to be groups of the nature of COOH , OH , NH_2 , or SO_3Na . The force field surrounding the dye molecule is asymmetric and the region of these groups has the more intense field. It is not possible to predict which one of the forms present on a given crystal will be stronger adsorbing solely on the basis of the relative field intensities of the forms, although this control is apparent with halite and in most cases of dye adsorption on alum. The adsorption of inorganic substances and dyes by growing crystals, with respect to the forms of the adsorbing crystal, quite generally varies with the nature of the adsorbate, and, in a given instance, may vary with the external conditions. The galena cubo-octahedrons cited earlier which are selectively incrustated on the (111) form on two specimens and on the (100) form on two other specimens, although galena has a NaCl type structure, and an analysis of the various incrustations on calcite with respect to the crystal forms, assuming these to be due to the adsorption of substance, clearly illustrates this. This behavior shows that in adsorption on a crystal it is necessary to consider the properties of both the adsorbing and adsorbed substances, as has been already noted, and, since this knowledge cannot be realized at present, the

³⁰ Buckley, H. E., and Cocker, W., *Zeit. Kryst.*, vol. **85**, p. 58, 1933. Further literature on the adsorption of dyes by crystals, with habit change, is cited in this paper.

adsorbing power of the forms on a crystal is best described as being specific for different substances.

ORIGIN OF SELECTIVITY ON NATURAL CRYSTALS

Among the examples of incrustations selective on the forms of natural crystals it is possible to distinguish two general types on the basis of the mode of deposition of the incrusting substance. One type is represented by the hematite on quartz, clay material on quartz and the iron oxide on calcite examples in which the deposited substance originally existed as a colloid in the solution surrounding the crystal and from which its particles were adsorbed by the crystal during or after the completion of its growth. These examples are analogous in their origin to the cases cited where artificially grown crystals have selectively adsorbed colloidal particles of dyes (or molecules of colloidal dimensions, in the case of some dyes) with the formation of a zonally colored crystal. The well known crystals of amethyst from Uruguay and Brazil which show in a basal section a distribution of color into three triangular sectors while the other three sectors are colorless, the sectors representing the horizontal projections of the faces of the terminating rhombohedrons, also appear to owe their color distribution to the selective adsorption of colloidal iron oxide by one of the rhombohedrons throughout the growth of the crystal. On the specimens which the writer has seen the colored sectors correspond to the positive rhombohedron.

In contrast to the preceding type the deposited mineral in the selective incrustations of albite on orthoclase, bournonite and chalcopyrite on galena, dolomite on calcite, etc., was not adsorbed as colloidal particles of an already defined substance but evidently crystallized from solution on the surface in question and grew to crystals of considerable size. The existence of the selectivity in this type is believed due to a selective adsorption of the substance from true solution, preceding crystallization, on certain forms of the crystal. Crystallization will tend to initiate on the strongly adsorbing forms since: (1) The concentration of the crystallizing substance will be greater there, because of the adsorption, than in the solution or on the adjacent forms of lower adsorbing power. This will favor the formation of crystal nuclei on that surface. (2) The work required for the formation of crystal nuclei on the adsorbing surface is smaller than in the solution because the free energy for

the formation of the surface of the nucleus adjacent to the adsorbent will as a rule be less than that required to form a surface of equal extent in the solution.³¹ (3) The adsorbate may be oriented at the interface. This would facilitate the development of the ordered structure of a crystal at the interface rather than in the randomly oriented interior of the solution. Molecular orientation at an interface is believed to be responsible for the increase in crystallization velocity observed at the gas surface of some super-cooled liquids³² and of water (during freezing) in sols containing non-spherical particles.³³ In the latter case the phenomenon is attributed to the orientation of the water molecules at the surface of the particles. Similarly it is found that in the crystallization of solutions in a magnetic field crystal nuclei appear more rapidly and grow faster. This is due to the orientation of the field on the molecules making it easier for them to enter the regular arrangement of a crystal lattice.^{34,35}

A regular arrangement of the adsorbate on the adsorbing surface, the pattern of the adsorbed substance following the pattern of the surface lattice units of the adsorbent, might also favor selective incrustation in that crystallization could be expected to start on planes of the adsorbing crystal whose atomic arrangement and spacing are closest to a principal plane of the crystals of the adsorbed substance. In parallel growths of two substances, by super-deposition, the surfaces of contact are like, or nearly like, planes; in for example, the oriented growths of alkali haloids on mica cleavages the planes of contact are mica (001) and haloid (111)

³¹ Freundlich, H., in Alexander, J., *Colloid Chemistry*, vol. 1, p. 588, 1926.

³² Söllner, K., *Kolloid-Zeit.*, vol. 59, p. 58, 1932.

³³ Freundlich, H., and Oppenheimer, F., *Ber. deutsch. chem. Ges.*, vol. 58, p. 143, 1925.

³⁴ Schaum, K., and Scheidt, E. A. *Zeit. anorg. Chem.*, vol. 188, p. 52, 1930. Samuracas, D., *Compt. rend.*, vol. 194, p. 1225, 1932.

³⁵ The orientation of organic molecules with an asymmetric field by adsorption at an interface, such as the orientation of alcohols or fatty acids at a water-air interface in which the high field —OH end of the alcohol molecule or the —COOH end of the fatty acid molecule goes into the water phase and the hydrocarbon end extends into the air, as studied by Langmuir, Harkins and others, seems to find a parallel in the mode of attachment of hemimorphic crystals to their matrix. Crystals of the common mineral calamine (orthorhombic-hemimorphic) are almost always attached by the antilogous end of the polar axis and this is presumably determined by the orientation of its asymmetric molecules by adsorption at the matrix-solution interface before the start of crystallization.

since these are almost identical geometrically. The oriented intergrowths, by unmixing or otherwise, in some sulphide minerals also take place on those planes in which the atomic arrangement and spacing are almost alike, both minerals sharing the structural plane at the contact.³⁶

Selective incrustations of the crystallization kind have been found only in nature and the origin of both these and the colloidal particle kind does not appear to have been previously recognized. The nearest approach to an experimental example is in an observation by Kreutz³⁷ that parallel growths of NaNO_3 seemed to be more perfect and easy to obtain on the (110) form of barytocalcite than on (001).

ACKNOWLEDGMENT

The writer takes this opportunity to express his gratitude to Mr. Herbert P. Whitlock for his courtesy in placing the facilities of the Department of Mineralogy in the American Museum of Natural History at his disposal and for assistance in the study of the crystallography of certain of the specimens described.

MEMORIAL OF GEORGES FRIEDEL

J. D. H. DONNAY, *The Johns Hopkins University*.

Another giant among crystallographers has passed away. Georges Friedel our distinguished honorary life fellow died at Strasbourg, France, on December 11, 1933. He was born at Mulhouse, France, on July 19, 1865. He was the son of the great French chemist and mineralogist, Charles Friedel (1832-1899) and the father of Edmond Friedel (1895-), the third of a dynasty of scientists.

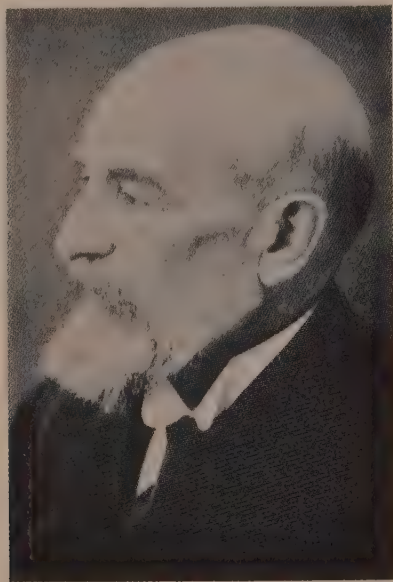
Georges Friedel was graduated from the Paris School of Mines, where he was the enthusiastic disciple of Ernest Mallard. He had a double career: in the French Bureau of Mines, he reached the high office of *Inspecteur général des Mines*; at the same time he was engaged in teaching and research, first at the Saint-Etienne School of Mines, later at the University of Strasbourg where he was appointed the head of the Mineralogical Institute. Since 1917, he was a correspondent of the French Academy of Sciences. His publications extend over a period of 43 years. Although they deal

³⁶ Gruner, J. W., *Amer. Min.*, vol. 14, p. 227, 1929.

³⁷ Kreutz, St., *Min. Mag.*, vol. 15, p. 233, 1909.

primarily with crystallography and mineralogy, they also include valuable geological contributions.

I. THE GEOLOGIST:—In 1902, he published a memoir on the "Firminy granite massif" and a geological map of the Saint-Etienne coal basin. In 1906–07, jointly with Pierre Termier, he showed the existence of nappes of pre-stephanian age in the Saint-Etienne region. With F. Grandjean, he published a further study of the eastern border of the "Plateau Central" (map of the Lyon



GEORGES FRIEDEL
1865–1933

quadrangle). In 1907, he was awarded the *Prix Joseph Labbé* by the French Academy for his contributions to geology and the leading part he played in the discovery of a new coal field east of Lyon. In 1919, again with P. Termier, he wrote three papers on the *klippes* of the Alais plain and the structure of the Gard coal field. In 1927, he reported on the presence of a salt dome in the Haut-Rhin oligocene basin. In 1929, with V. Maikowsky, he published very pertinent notes in geophysics on temperature measurements in drill holes.

II. THE MINERALOGIST:—G. Friedel achieved the synthetic production of a number of minerals. He began this investigation in 1890 with his father. The action of alkalies on mica gave them nepheline, sodalite, leucite, orthoclase, and anorthite. In 1909 (with F. Grandjean) chlorites were obtained by the reaction of alkaline solutions on pyroxene. In 1912, he prepared artificial potassium nepheline. He solved the riddle of the chemical nature of melanophlogite. His famous work on zeolites dates back to 1896–7; among other things, he showed the possibility of substituting various liquids or gases for water in zeolites and made the classic comparison of considering a zeolite as a sponge, able to release and again take up water, so well explained by recent X-ray studies. He investigated the etch-figures and percussion figures of mica, and the etch-figures of quartz at high temperatures. With F. Grandjean, he gave a paper on tin-bearing rutile. He reported the abundance of octahedrite in chloritized schists and granites. He also reported on analcime, on a new variety of calcite, on compact muscovite, described several new crystalline species, and found new localities for a number of rare minerals.

In later years, he became greatly interested in the diamond and published several papers on that subject: on the black inclusions of the Cape diamond; on the symmetry, forms, and habit of the diamond; on its birefringence, and (with G. Ribaud) on an allotropic transformation of diamond into graphite. Among his last publications, his paper on malformed halite crystals typically illustrates the rigid scientific honesty of his method of investigation.

III. THE CRYSTALLOGRAPHER:—In 1893, Friedel developed a new method for the accurate measurement of path-difference based on the restoration of elliptically polarized light to plane polarized light. His ingenious procedure has recently been applied to the study of stressed glass by R. W. Goranson and L. H. Adams.

Along with his work on twinning, begun in 1897, Friedel carried on his celebrated studies on the *Law of Bravais*. This law had been enunciated by Bravais on theoretical considerations. In 1904, Friedel announced that it was a law of observation, independent of any speculation. His classic paper of 1907, with numerous examples, convincingly settled this point and the Law of Bravais has since then received general acceptance. Although Friedel, in his deep modesty, actually credits Haüy for having first sensed the

truth of this law, it would not have been recognized had it not been for his own observations; the Law of Bravais is truly Friedel's law. In 1905, the French Academy of Sciences chose him as the laureate for the *Prix Delesse* in recognition of his crystallographic work.

Friedel's *Law of mean indices* (1908) discloses the fact that the axial elements of a crystal can be approximated simply from the list of observed crystal forms. This is another proof that the reticular density of a face is the chief factor controlling its occurrence. When Friedel, by his patient and sagacious observations, definitely established the factual character of the Bravais principle, he laid the foundation of morphological crystallography on a firm experimental basis.

Friedel's excellent discussion of the experimental bases for a reticular hypothesis of crystal structure and his lucid explanation of the difficult question of irrational trigonal axes justified A. F. Rogers' statement¹ that Friedel's *Law of rational symmetric intercepts* (1905) had "practically proved" the existence of a space-lattice in crystals before Laue's decisive experiment.

Friedel was the first to outline the theory of the *crystallographic bundle of planes* (*faisceau, gerbe*) (1905). This paved the way for the large memoir of Zaremba and Kreutz (*Fondements de la Cristallographie géométrique*) whose results were further generalized by R. Gibrat (1927). The basic importance of Friedel's *faisceau complet* is well expressed by Gibrat, who sees in it the very essence of crystallography.

The Mallard-Friedel theory of twins is by far the most satisfactory that has been advanced. Summarized in Friedel's *Leçons* (1926), it is also available in German in Niggli's textbook. The leading principle is that twinned crystals have a lattice in common, which pervades the whole of the complex crystalline edifice. The prolongation of the common lattice from one member of the twin to an adjacent member may be either exact or approximate; in each case the unit cell of the common lattice may be either the smallest cell of the individual lattices of the twinned crystals or a simple multiple cell thereof. Hence Friedel's classification of twins falls in four classes. The theory accounts for all types of twins but one: the Zinnwald twin. Friedel's very last paper (1933), in which he correlates the observations of J. Drugman on the various quartz twins with the experimental results of Gaubert, Schaskolsky and

¹ *Am. Mineral*, vol. 10, pp. 181-7, 1925.

Schubnikow, explains the hitherto irreconcilable exception. In the Zinnwald twin, two preexistent crystals unite in such a relative orientation that the two faces in contact have one parameter (a lattice-row) in common. Friedel calls this type of twin *monoperiodic* in contradistinction to the usual kind of twins, to be termed *triperic*. Moreover, he points out the possibility of a third type (*diperiodic*) in which the adjacent individuals would have a two-dimensional cell (a plane lattice) in common.

Incidentally, the Mallard-Friedel theory of twins shows the true value of merohedry. The expression "deficient elements of symmetry" may be misleading but the concept of merohedry (duly divorced from it) cannot be discarded for it emphasizes the fundamental distinction between the symmetry of a crystal and that of its lattice—the key to the explanation of twinning.

Friedel began his work on the so-called *liquid crystals* in 1907 and continued it until 1931. He had various co-workers and followers (F. Grandjean, L. Royer, his son E. Friedel, C. Mauguin, Foex, etc.) and their contributions are perhaps the most outstanding ever published in Lehmann's field. Friedel recognized four different *stases* (structural types) of matter: crystalline, smectic, nematic, amorphous. They are separated from each other by *discontinuous transformations*, which is the basis of the classification. Here again, Friedel's work will stand since it is based on careful observation of facts under the microscope.

Friedel was one of the first to grasp the value of the new tool placed at the disposal of crystallographers by Laue's experiment. As early as 1913, he gave the correct proof of the law that X-ray diffraction is equivalent to a "reflexion" from reticular planes and showed that it could be derived from two hypotheses only (not three as Wulff had thought). The fact that a radiogram cannot tell whether a crystal is centrosymmetric or not is also due to Friedel (1913), who listed the eleven symmetries possible in an X-ray picture; this contribution is called Friedel's law in Bragg's new book. We are also indebted to him for valuable notes on the calculation of the intensity of diffracted X-rays (1919). His textbook (1926), which gives a clear presentation of the essentials of structural crystallography, includes a detailed treatment of several questions little known at the time.

In physical crystallography, we are indebted to Friedel for his remarkable theory of crystal growth (1924), showing the exact

similarity of crystal corrosion by a slightly undersaturated solution, and crystal growth in a slightly supersaturated solution. The two phenomena are symmetrical with respect to the saturation point. The theory explains the formation of "negative crystal" or cavities (in crystals) bound by crystal forms, also the formation of curved faces by convergent or divergent diffusion (*effet d'angle*, *effet d'arête*). Friedel discussed and explained the failure of the former Curie-Wulff theory. His work on crystal corrosion has been continued by R. Weil (etching of negative crystals in quartz by HF).

In 1927, Friedel showed that the presence of holoaxial hemihedral forms on a crystal does not warrant the conclusion that the crystal has hemihedral symmetry. This is due to the fact that, since an optically active substance is devoid of symmetry planes, a crystal (otherwise holohedral) grown in such a substance cannot show any plane of symmetry, but can at the most exhibit holoaxial hemihedry. In 1930, jointly with R. Weil, Friedel pursued his work on the influence of the medium of crystallization on the symmetry of the crystal forms developed.

Let us also remark that L. Royer's remarkable investigation on *épitaxie* (mutual orientation of crystals of different species) of 1928, carried on in G. Friedel's laboratory, seems to have found its inspiration in Friedel's ideas on the subject as expressed in his textbook of 1911.

IV. THE TEACHER:—The achievements of the many students of G. Friedel testify to the excellence of his teaching. He published three textbooks: (1) *Cours de minéralogie*, Ecole des Mines de Saint-Etienne, 211 pp., 1904; (2) *Leçons de Cristallographie*, 310 pp., 383 figs., Paris, Hermann, 1911; (3) *Leçons de Cristallographie professées à la Faculté des Sciences de Strasbourg*, 602 pp., 578 figs., 1926. The latter is partly a revision of the second. It is now an outstanding text in geometrical and physical crystallography.

Friedel's brilliant qualities as a teacher are displayed in the layout of this book, the right emphasis placed on fundamentals rather than on mere accumulation of facts and theories, a highly critical scientific attitude, an illuminating discussion of what is known followed by the challenging outline of what remains to be found. The charm of the book is further enhanced by the elegant simplicity of its language. Very few literature references are found in Friedel's *Leçons* although due credit is given to all investigators except

Friedel himself! The old master wanted to mark his disapproval of the abuse of bibliography in teaching, which he thought was carrying us back to the medieval practice of rehashing bookish gossips.

The greatest lesson which emanates from his text as well as from his life work is the importance of meticulous observation and scrupulous acceptance of duly observed facts.

Even from this incomplete survey of Friedel's scientific contributions, one cannot fail to be impressed by the magnitude of his work as well as the fundamental nature of the problems he solved. None of the important questions of crystallography at issue during the past half-century escaped his inquisitive attention and his name remains attached to several natural laws.

The indomitable energy with which he carried on his work during his long illness gave the measure of his moral fortitude. In Georges Friedel, the man was equal to the scientist.

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See also: *Ann. Soc. géol. Belgique*, vol. 29, Mém. 237, 1902; vol. 45, Bull. 234, 1923; Livre jubilaire 1924 (geology, diamond). *Bull. Soc. Ind. Min.*, Saint-Etienne (4) vols. 3-4, 485 pp., 1904 (twins). *Bull. Soc. géol. France* (4) vol. 6, p. 240, 1906; vol. 7, p. 191, 1907; vol. 23, p. 488, 1923; *Bull. Serv. Carte géol. France*, vol. 20, 1910 (geology). *Jour. Chimie phys.*, vol. 11, p. 478, 1913 (Curie theory). *Annales Phys.*, vol. 18, p. 274, 1922; *Bull. Soc. fr. Phys.*, 1922, 1924, 1926; *Revue gén. Sc. pures et appl.* vol. 36, p. 162, 1925; *Jour. Phys. et Radium*, (6) vol. 3, (12); (7) 2 (5); *Z. Krist.*, vols. 72, 73, 79, 83 (liquid crystals). C. R. Congrès Soc. savantes, Strasbourg, 1920 (twinning).

NOTES AND NEWS

NOTES ON STAUROLITE AND ASSOCIATED MINERALS FROM SCHIST AT GASSETTS, VERMONT

L. W. CURRIER*

A certain garnetiferous mica schist in south-central Vermont has been named Gassetts schist by C. H. Richardson¹ from the excellent exposures near Gassetts station in Chester township. For the

* Published by permission of the Director of the United States Geological Survey.

¹ Richardson, C. H., The geology and petrography of Reading, Cavendish, Baltimore and Chester, Vermont: *Report of the Vermont State Geologist*, 1927-28, p. 225.

greater part, as mapped, the highly mineralized portion appears to be a relatively narrow border facies of his Cavendish schist at its contact with what he believes to be an orthogneiss intrusive into the regional schists. Furthermore, these schists are considered to be of Middle or Upper Cambrian age because of their stratigraphic relationships to the Lower Ordovician (Beekmantown) beds as traced from areas where fossil evidence has been obtained. Intrusives of granite, pegmatite, aplite, and basic rocks are numerous in the region in which these Cambrian (?) schists are exposed.

Because of its impressive appearance and its mineral content, the mica schist at Gassetts should be of considerable interest to amateur mineralogists as well as to professional geologists. The brief description given here is intended chiefly to indicate its interesting mineralogic character, especially as regards the staurolites of rather unusual habit. The list of minerals is doubtless not complete but should serve to stimulate search for showy material and for other mineral species in the formation.

At the type locality, near Gassetts's station, the rock is a silvery white garnetiferous mica schist of very striking appearance. Fresh cuts, when bathed in sunlight, present a brilliant and dazzling effect. Old cuts and exposures are duller, but the material is still distinctive. The rock is highly schistose because of the predominance of parallel plates of mica. Interfoliated with the layers of mica are more or less lenticular and discontinuous layers of clear granular quartz.

The following minerals are common in the schist: Muscovite-paragonite, quartz, staurolite, garnet (almandite), kyanite, tourmaline, chlorite, biotite, magnetite, rutile, and zircon.

The metamorphism of the schist is not closely restricted to igneous contacts, but igneous rocks are abundant in the region and the highly metamorphosed portion of the schist follows in general the contact of a somewhat less metamorphosed schist with a granitic gneiss that may be of intrusive character. Although staurolite, garnet, and kyanite are generally indicative of so-called regional or dynamic metamorphism, the presence of abundant tourmaline, in places, suggests that igneous influences may have been prominently active. Possibly, too, the uncommon habit of the staurolite is related to such conditions of metamorphism. At any rate it appears that the process of metamorphism may not have been as simple as is commonly understood by the term "dynamic

metamorphism," even though the mineralogic character of the rock is, except for the tourmaline, characteristic of many regional schists.

The staurolite presents an interesting crystallographic feature which seems worthy of special emphasis. The crystals display an uncommon habit, being thin tabular parallel to the brachypinacoid which is the dominating form. Other forms are the unit macrodome, forming sharp terminations, and the unit prism, developed as narrow faces (Fig. 1). Although this habit, in which the crystals are tabular parallel to $b\{010\}$, is not unknown elsewhere, it is apparently rare and is markedly different from the usual habit of staurolite in regional schists, such as are known in Virginia, Georgia, and elsewhere. Some staurolite crystals of the familiar stout prismatic habit with basal pinacoidal terminations are also to be found. Very few staurolite twins are present, and these are not of the common cruciform type, but apparently have a pyramidal twinning plane. The staurolites are mostly less than one centimeter in greatest dimension, fresh, sub-transparent to transparent and of dark reddish-brown color. They lie roughly parallel to the planes of foliation. A number of crystals were examined by W. T. Schaller of the U. S. Geological Survey, who has reported the following data:

"The average of the measured angles compared with those calculated from the axial ratio² $a:b:c = 0.4725:1:0.6806$, $p_0 = 1.4404$, are as follows:

MEASURED AND CALCULATED ANGLES FOR STAUROLITE FROM VERMONT

Forms	Measured				Calculated			
	ϕ		ρ		ϕ		ρ	
	°	'	°	'	°	'	°	'
$b\{010\}$	0	01	90	00	0	00	90	00
$m\{110\}$	64	40	90	00	64	43	90	00
$r\{101\}$	90	06	55	11	90	00	55	14

"There is a good cleavage parallel to $b\{010\}$. Some faces of $r\{101\}$ are faintly striated parallel to the intersection edges $r\{101\}:b\{010\}$.

"Crystals of staurolite flattened parallel to $b\{010\}$ are not com-

² Goldschmidt, V., *Atlas d. Krystallformen*, Text, vol. 8, 1923, p. 76.

mon. They were described by Weiss³ who illustrates a crystal tabular to $b\{010\}$ with the additional forms: $\{001\}$, $\{110\}$, $\{1.0.10\}$, $\{106\}$, $\{101\}$, and $\{201\}$. Weiss also states that stauro-lite crystals from the Tirol have been described as tabular after $\{010\}$ by others."

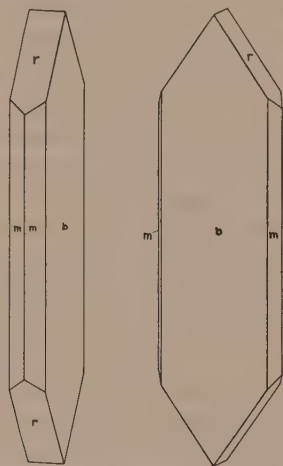


FIG. 1. Tabular habit of stauro-lite in the schist at Gassetts.

The muscovite is worthy of particular mention because of its content of soda. Two samples of carefully separated material were analyzed in the chemical laboratories of the United States Geological Survey for alkalis and silica with the following results:

	I	II
Na ₂ O	4.65	3.24
K ₂ O	2.49	6.01
SiO ₂	44.25	47.16

Analyses were checked on each sample. The excess silica chiefly represents quartz. Sample No. I was slightly less pure than No. II. A very small amount of chlorite was present. The two samples were taken from different parts of the same outcrop. It is clear that the paragonite molecule enters largely into the composition of the mica, which varies within the isomorphous series muscovite-paragonite and in part is dominantly paragonite. The refractive

³ Weiss, Karl, Der Stauroolith in den Alpen: *Zeitschr. Ferdinandeums für Tirol u. Vorarlberg*, vol. 45, p. 134, 1901.

indices are doubtless variable. Two samples examined by Jewel Glass gave (1) $\gamma = 1.602 \pm 0.001$ and $\beta = 1.598 \pm 0.001$; (2) $\gamma = 1.605$ and $\beta = 1.600$. Further study of the mica in field and laboratory, with complete chemical and optical analyses is planned, but it seems appropriate to present the preliminary results at this time.

The garnet porphyroblasts are commonly less than one centimeter in diameter, but have been reported several times as large. They display the common unmodified dodecahedral habit, and, with care, well-formed crystals may be obtained. The deep red color and index of refraction of 1.80 ± 0.01 indicate the almandite species in which the pyrope molecule is present in minor quantity. For the most part the crystals are fresh and free of shearing effects. A very subordinate number show association with peripheral chlorite which may be an alteration product. The mineral is of general distribution in the formation.

Kyanite is present as greenish-gray, stout, lath-shaped or bladed crystals up to 2 or 3 centimeters in length. It is not well distributed but rather of localized development.

Tourmaline crystals are abundant in parts of the formation, but its distribution is spotty. The mineral is the black variety with characteristic crystal development. The individuals are generally less than one centimeter in length; many of them are of microscopic size. Under the microscope the color of the ordinary ray is deep green, of the extraordinary ray, pale brown. The indices determined were as follows: $\omega = 1.652 \pm 0.002$, $\epsilon = 1.621 \pm 0.002$. The variety is probably dravite.

Green chlorite is distributed in the rock as small, rather inconspicuous foliae, in part peripheral to the garnet crystals of which it may constitute an alteration product. It is optically (+), $\beta = 1.613 \pm .002$, and the birefringence is very low, probably about 0.002. The variety is rapidolite according to Winchell's classification. Greenish-brown biotite is generally inconspicuous and not abundant.

Magnetite is distributed as very small black anhedral grains, and not conspicuous; the rutile and zircon are entirely microscopic and rare.

At Gassetts a mill has been constructed for the crushing of the schist and the separation of mica and garnet. The mill was not in operation at the time of the writer's visit but good concentrates of garnet, mica, and staurolite were seen.

A SIMPLE AND INEXPENSIVE PROJECTION SHEET FOR
GNOMONIC AND STEREOGRAPHIC PROJECTIONSA. L. PARSONS, *University of Toronto.*

During the past summer it became necessary for the Department of Mineralogy in the University of Toronto to replenish its supply of projection sheets for plotting the results of goniometric measurements. In view of the state of foreign exchange the former source

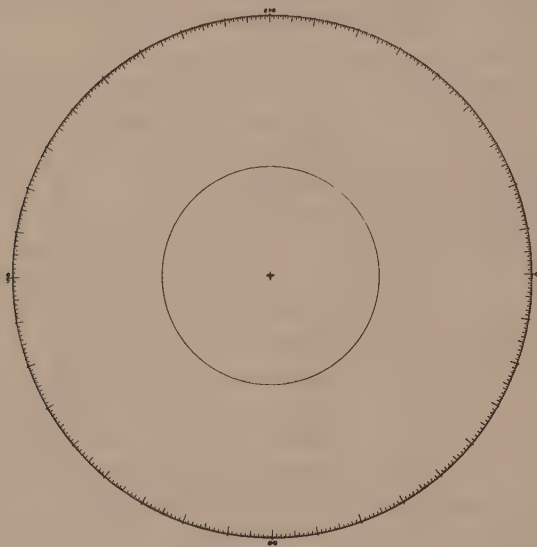


FIG. 1

of supply was too expensive to consider. The result of the consultations by members of the staff is the projection sheet, shown in figure 1, consisting of two concentric circles, one with a radius of 5 cm. and the other graduated in half degrees, with a radius of 12 cm.

With straight-edge and compasses both ϕ and ρ values can readily be plotted direct, and with the additional help of a millimetre scale any crystallographic problem may be solved graphically. The graphic determination of $5 \tan \rho$ and $5 \tan \rho/2$ with the projection of the unit pyramid of anglesite in both gnomonic and stereographic projection is shown in figure 2.

From the teaching standpoint a great advantage of the present sheet is that it is a good quality drawing paper so that errors in projection may be corrected without marring the appearance of

the surface of the paper. It also gives the opportunity to show the principles of projection without reference to special tables. The student is much more likely to understand the meaning of the distances that he measures from the pole if he has protracted the required tangent than if he has looked up the value in tables. His errors will certainly be reduced.

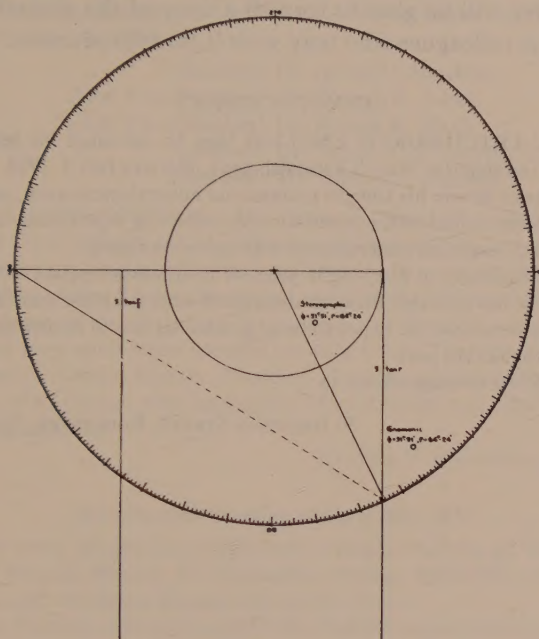


FIG. 2

For those who prefer a different scale for their projections it is only necessary to describe a ground circle of the required diameter.

The cost for 200 sheets was as follows:

Draftsman's time, 1 day.....	\$ 5.00
Zinc etching.....	10.00

\$15.00

Charge 20% original cost to first 200 sheets.....	\$3.00
200 sheets drafting paper 14" square.....	4.22
Print.....	1.00

\$8.22

Cost per sheet..... 4.11¢

If the entire cost of the cut be charged to the first 200 sheets the cost is 10.11¢ per sheet which is almost exactly the cost of the sheets formerly used at the rate of exchange prevailing at the time, without the additional charges for packing, express and customs duties. In this case the cost of future supplies will be less than 3¢ per sheet.

The writer will be glad to furnish a copy of the projection sheet to any of his colleagues who may wish it for reproduction.

ANNOUNCEMENT

GEORGE LETCHWORTH ENGLISH begs to announce his resignation as *Consulting Mineralogist* of Ward's Establishment, effective July 1, 1934.

He expects to devote his time to professional mineralogical work, including appraisals of mineral collections, mineral surveys, collecting expeditions, technical aid to mineralogical museums, mineralogical writing and lecturing.

With a background of forty-eight years of continuous contact with minerals, during which he has probably handled and valued more scientific minerals than any other living mineralogist, he hopes to be of greater service to mineralogical science in the future than in the past.

Kindly address correspondence to

50 BRIGHTON STREET, ROCHESTER, NEW YORK

PROCEEDINGS OF SOCIETIES

NEW YORK MINERALOGICAL CLUB

Minutes of the Meeting of March 15th, 1933

A regular meeting of the New York Mineralogical Club was held at The American Museum of Natural History on the evening of March 15th, 1933. The attendance was 85. President Hawkins was in the Chair.

President Hawkins exhibited a specimen of brown tourmaline found near the Harlem River Ship Canal at Kingsbridge, New York City.

The Nominating Committee presented the following names to serve as officers of the Club for the year 1933-34:

President: Dr. Alfred C. Hawkins

First Vice-President: Mr. George E. Ashby

Second Vice-President: Dr. Horace R. Blank

Secretary: Dr. Daniel T. O'Connell

Treasurer: Mr. Gilman S. Stanton

The speaker of the evening was Mr. James G. Manchester, the distinguished author of the Club's bulletin on "The Minerals of New York City and Its Environs." Mr. Manchester's interesting talk was supplemented by means of lantern slides in color, the subject being "Some Interesting and Notable Mineral Specimens." Included were many of the plates from his book on New York City minerals, as well as some of the more notable specimens in the collections of the Club and The American Museum of Natural History. President Hawkins expressed the enthusiastic appreciation of all present when he thanked Mr. Manchester on behalf of the Club for his excellent address.

DANIEL T. O'CONNELL, *Secretary*

Minutes of the Meeting of April 19th, 1933

The New York Mineralogical Club held a regular meeting at The American Museum of Natural History on Wednesday evening, April 19th, 1933. The attendance was 100. President Hawkins was in the Chair.

President Hawkins called attention to the Bulletin of the Mineralogical Society of Southern California, copies of which were received recently by the Secretary. The officers presented by the Nominating Committee were unanimously elected to serve for the year 1933-34.

The speaker of the evening was Mr. Samuel George Gordon, Associate Curator, Department of Mineralogy, The Academy of Natural Sciences of Philadelphia, who described his experiences collecting minerals for the Philadelphia Academy on the "Fourth Academy-Vaux Mineralogical Expedition across South America and Africa." This very interesting travelogue and narrative was illustrated by means of colored lantern slides at the close of which a rising vote of thanks was tendered Mr. Gordon.

Mr. James F. Morton exhibited some specimens of titanium-colored blue quartz and rutile from Nelson County, Virginia, also zircon and beryl crystals from North Carolina.

DANIEL T. O'CONNELL, *Secretary*

On April 28th a special Testimonial Meeting to Dr. Edward Salisbury Dana was held by the New York Mineralogical Club at the American Museum of Natural History. On this occasion the retiring President, Dr. Alfred C. Hawkins, presented to Dr. Dana a certificate of Honorary Life Membership in the New York Mineralogical Club "in recognition of his eminence in the science of Mineralogy in which he has been for many years a leader, teacher, and author."

PHILADELPHIA MINERALOGICAL SOCIETY

The Academy of Natural Sciences of Philadelphia, May 3, 1934

President Gillson called to order the regular meeting of the Philadelphia Mineralogical Society, 46 members and 40 visitors being present. The following were elected to membership: Messrs. J. Warren W. Worthington, Martin L. Ehrman and Adolph E. Meier; Juniors: John Anderson, Emile Moraux and George Mershon.

Mr. Harold W. Arndt reported 32 persons in 8 automobiles took part in the field Trip of April 29, visiting Bridgeport, Henderson Station, Howelville and Phoenixville, Pa. Specimens obtained included quartz and calcite crystals, limonite geodes, limonite pseudomorph after pyrite, graphite, fluorite, sphalerite, galena, pyromorphite, wulfenite, chalcopyrite, cuprite, cerussite, anglesite, ankerite and barite.

Mr. David Walker announced that the 40 year old Worrell Mineral collection recently presented to the Frankford Mineralogical Society would be displayed in the Frankford Dispatch window until May 14.

Mr. Stephen Varni exhibited the largest and clearest green tourmaline crystal ever found at Mt. Mica, Maine. It is uncut, weighs 422 carats, and would cut a flawless stone of 200 carats. He described its finding by Mr. Merrill in the late nineties. Dr. E. H. Payne described the acquisition of a flawless piece of citrine quartz, uniform in color, weighing 14 oz., from a native in Brazil. It would cut a perfect square stone of 10 oz., or a pear shaped one of 12 oz.

Dr. Edgar T. Wherry moved that a committee be appointed to invite the Pennsylvania Field Conference of Geologists to hold their May 1935 meeting in or near Philadelphia.

Professor Lincoln Dryden of Bryn Mawr College, addressed the Society on *Rock Correlation by Heavy Minerals*. The source and age of sedimentary beds may be determined by correlating the minerals having a specific gravity greater than 2.9, contained in the sediments. By this method rocks formed in one drainage basin can be correlated. The most thorough work by this method has been done in the southwestern part of England on the Dartmoor Granite. The method has been used successfully in connection with the water supply near Trieste, also in Oil Field work. The Society gave Prof. Dryden a rising vote of thanks for his splendid presentation.

W. H. FLACK, *Secretary*